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UPSTREAM CONTROL OR CONTROL FROM DOWNSTREAM OF CANALS AND CONDUITS

A Translation of

Commande par L'Amont ou Commande a partir de L'Aval en Canaux et Conduites

By

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Translated by

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Denver, Colorado
July 1950

TRANSLATOR'S PREFACE

This translation is neither complete nor final but practically all the ideas expressed by the original author can be obtained from it in its present form. The illustrations have been duplicated from the original article without translation of the descriptive material or reduction of values to English units.

CHAPTER I

GENERALITIES CONCERNING THE TWO METHODS

In discussing the problem of gravity distribution systems the subject may be divided into two major parts; one concerning canals and the second, conduits. Only the second part is of interest to us herein since we are faced with the design of the Oran Aqueduct.

Actually, so far as the control of discharge is concerned, there are many analogies applicable to either canals or conduits. The distinction we wish to make here is between canals or conduits where the discharge is set or regulated at the head end in a fashion which more or less faithfully follows the users downstream and canals or conduits where the regulation of discharge responds automatically and instantaneously to the actual demand of the users.

In the first case the supply take-off furnishes a certain discharge which is either its capacity or a discharge controlled by the ditch rider. This discharge is usually different from the exact needs of the users connected to the installation. We will call such an arrangement "upstream regulation." According to this definition one can say symbolically that rivers are subject to upstream control and likewise for artificial canals in general. Most of the distribution systems in use today are also controlled upstream.

In the second case, the discharge released at the head of the installation depends upon the demand and adjusts itself exactly and automatically. Since it is the demand of the users which effectively controls the discharge beginning from the downstream portion, we will say that such a distribution is "controlled from downstream."

We do not know at this time of any system of this latter type for canals. However, the system is under study and the construction of large canals in Morocco based on the principle is a project under study at the Dauphinois Laboratory (Neyrpic Laboratory). In the case of large conduits we can cite the irrigation network of Hamiz and the conduit portion of the irrigation network of the Oued Fodda.

These two networks situated in Algeria showed to the Colonization and Hydraulic Service the proper path to follow in the case of the supply of Beni-Bahdel at Oran. Despite the unusual importance of this supply the choice was made for control from downstream because of the necessity for having at one and the same time a security and a flexibility which a nonautomatic control upstream would not give.

To bring out the reasons for such a decision it is pertinent to present the essentials of the two methods. This is the object of the first chapter. We will speak first of canals with upstream control and then of conduits controlled in the same way. We will then describe the principle of conduits with control from downstream (such as that of Beni-Bahdel-Oran) and of certain canals in the project stage which will operate on the same principle.

I. The Example of Nature and Upstream Control

We have indicated previously that upstream control can be applied to canals and conduits. However comparatively this control applies easily to the first, it also is less well adapted to the second. We will develop this point of view rapidly.

A. Canals with Upstream Control

For the same discharge capacity and wall roughness a canal is usually clearly cheaper than a conduit not only because it is easier to build but also because it creates a particularly small head loss (for equal sections its wetted perimeter is smaller). A canal leads to the economical solution of many supply problems.

If no obstacles are placed in the canal and if it is long enough, the water surface is practically parallel to the bed. The loss of head distributed linearly along the canal is then always the same regardless of the discharge being carried. The water surface increases in proportion to the discharge but the loss of head remains uniformly distributed; it is equal to the slope of the canal. This remark which seems self-evident will have great importance in the rest of our discussion.

In the particular case of delivery of potable water from sources at a high elevation it must be remembered that filtration constitutes a new technique. Our ancestors were interested only in finding sources of water for urban supply. Since they used little pumping for want of energy they started searching from the town to be supplied and were often led a great distance. The old classical solution for delivering drinking water was the transport by gravity in a long covered canal. However, the source supplied the need and the general characteristic of the old delivery system was that the discharge was defined at the head end by natural conditions; man did not intervene.

As for modern canals, they are designed usually to transport nonpotable water and are uncovered. In the general case of irrigation canals it is necessary to establish a level above the terrain to be irrigated so that each take-off may function by gravity. To attain this end there are available the two following methods: by the artificial raising of the level in a canal constructed at a lower level or by raising the canal itself. The first method utilizes fixed or movable barriers which modify the natural flow, Figure 1. Regarding movable barriers the automatic gates with constant level upstream which are widely used for the Algerian networks seem to be in the direction of progress, Figure 2.

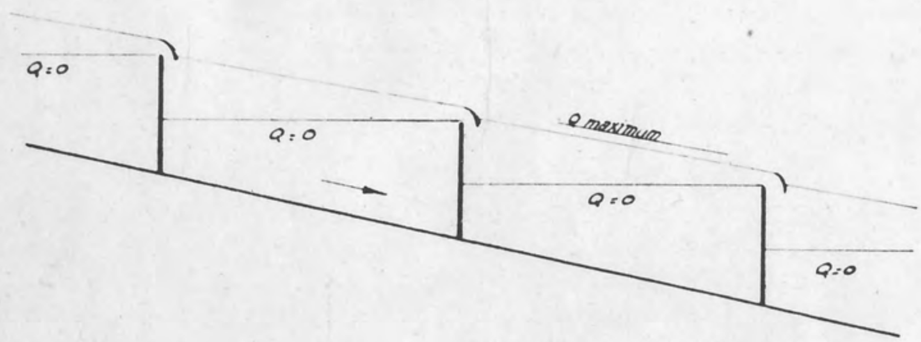
Also in Algeria the extra elevation of concrete canals is widely used. This method has been used a great deal in Morocco and Tunisia where the precast elements of prestressed concrete permit spans of the order of 7 meters (23 feet).

Actually the two methods described are not conflicting but conjugate. In relatively flat terrain the best solution seems to be the use of raised flumes which are kept practically full even for small discharges.

An ordinary canal is empty if it is not discharging. If by use of check barriers the canal is not completely empty when stopped it is still true that to increase the discharge it is necessary not only to turn in the increased discharge at the head end but in addition a volume of water must be released to increase the volume of water held in the canal so that it will be put into condition to function.

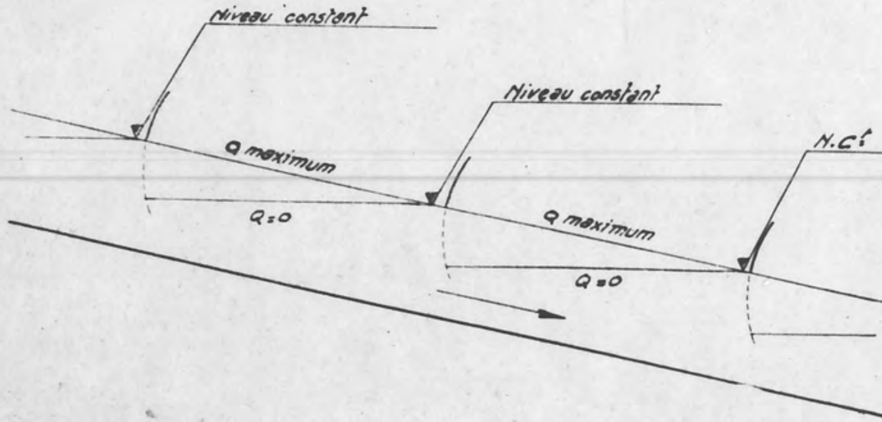
We wish to emphasize the fact that the volume of water held in a canal with upstream control varies in the wrong direction. When the user demands more water it is necessary to start by turning out in advance at the head end a discharge greater than the increase in demand. The user is well aware that his turnout is very slow. This is the nature of the thing. If one wishes to offset this inconvenience to some degree by means of a systematic refilling through raising the water level it is necessary to modify radically the mode of flow to change the sense of the variations in volume as a function of variations in demand. Let us not anticipate ourselves; such an inversion will be described in connection with control from downstream.

Flow in canals with upstream control is controlled by laws of sufficient simplicity that their functioning is generally correct. One can point out their slow response and the lack of flexibility which results therefrom. A more serious aspect of the same question should be emphasized; it is impossible to regulate the discharge turned out to correspond to the total discharge required by the users scattered over the system. In fact, the downstream end of the secondary laterals transmit nearly always directly into the drainage canals an excess discharge that no user has need for. Such losses are deplorable in a country where water is scarce.



CANAL EN COMMANDE PAR L'AMONT
AVEC BARRAGES SUCCESSIFS

Fig.nt: 1



CANAL EN COMMANDE PAR L'AMONT
AVEC VANNES SUCCESSIVES
SANS PERTE DE CHARGE A DEBIT MAXIMUM

dessiné : Colombat 4907?6

Fig.nt: 2

dessin n° I.D. 1536

Alimentation des canaux tertiaires à partir des secondaires dans des réseaux d'irrigation en «commande par l'amont». A gauche vanne maintenant un niveau amont constant ; à droite module à masque permettant le prélèvement d'un débit fixé.

Despite the inconveniences noted it remains that a canal with upstream control is a perfectly simple solution and as a result a good one. If the terrain crossed is fairly smooth the slope of the canal is regular and there is little trouble connected with the general alignment. Hydraulic operation introduces only simple phenomena. But to accomplish a regular slope in a region of irregular relief requires an alignment which becomes more serious as one tries to avoid earthwork and works of art. Among the works of art we have known all the majestic Roman arcades which served to avoid long detours or to span depressions.

We know less about the siphons also used by the Romans; their use was the first appearance of a new method of delivery always with upstream control which we will now describe.

B. Conduits with Upstream Control

Let us consider an element of an inverted siphon joining two reaches of a canal (Figure 3) and we have an example of a conduit with upstream control. To pass a discharge of "U" requires a total head of "h." For the maximum discharge this head is entirely dissipated as a loss of head distributed linearly along the conduit. The piezometric line AB represents the distribution of pressure in the conduit. When the discharge turned in at the head end decreases the essential difference between a pressure conduit and an ordinary canal shows up. This difference derives from the fact that the contents of a section under pressure cannot diminish (as contrasted with what happens in a canal when the discharge decreases). It is then the head loss, linearly distributed which decreases and there remains an excess of drop to be dissipated.

In the conduit with upstream control represented in Figure 3 this dissipation of the excess head is automatically taken care of in the first portion of the conduit where the flow is modified. There the water cascades and we revert to flow in a canal as studied previously. There is a junction at point D of Figure 3, cascade flow to pressure flow and the point varies from C to F as the discharge changes from its maximum to zero. One may think of a rotation of the hydraulic gradient around a point situated at the downstream end and a lowering of the gradient in proportion to the decrease in discharge.

The longitudinal profile may be more complicated than the one just described. It may be as shown in Figure 4 where there is a high point above the exit. Such a profile leads to various difficulties in operation.

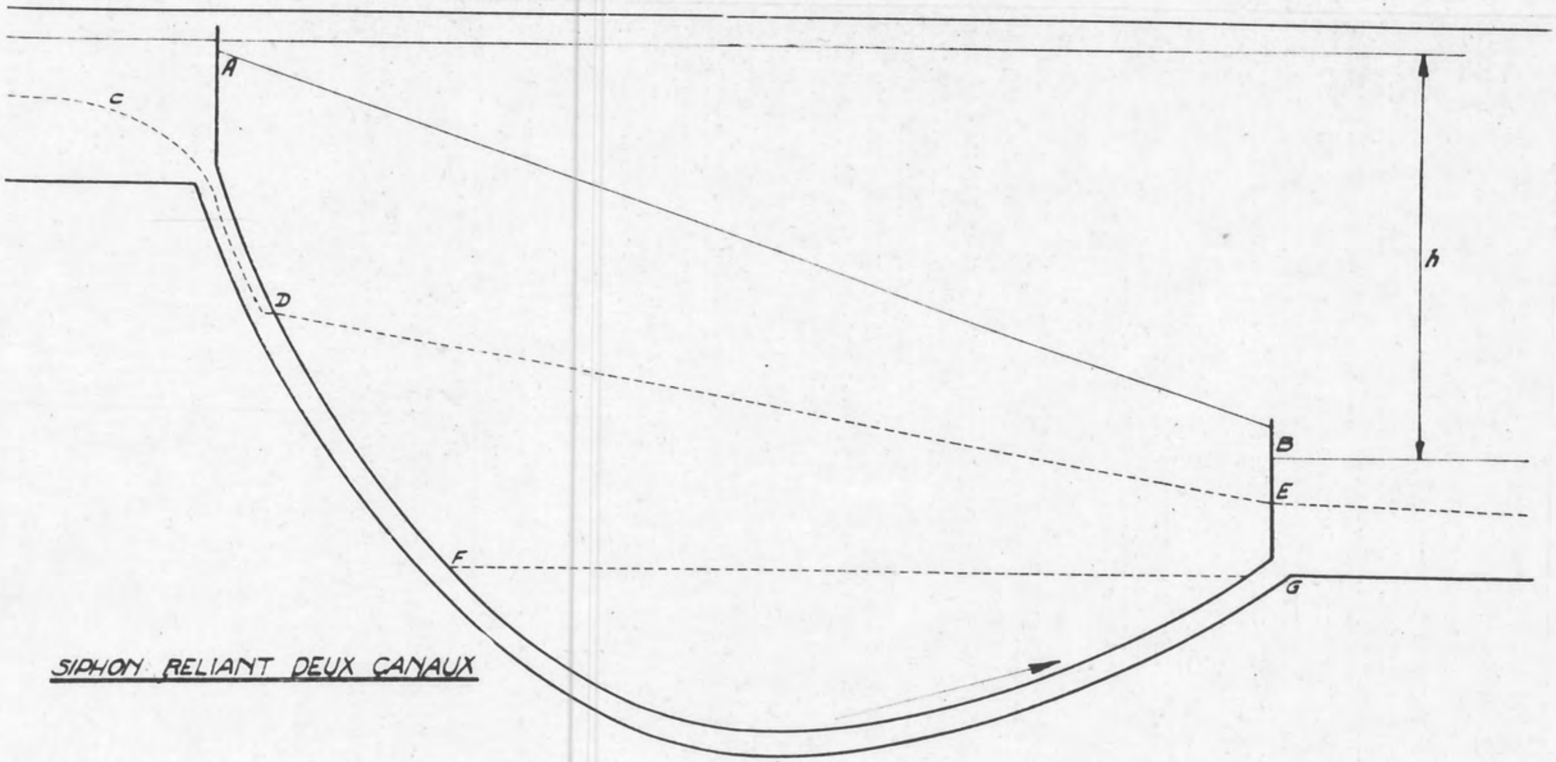


Fig. n° 3

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dessin n° I.D 1540

CONDUITE EN COMMANDE PAR L'AMONT AVEC UN POINT HAUT

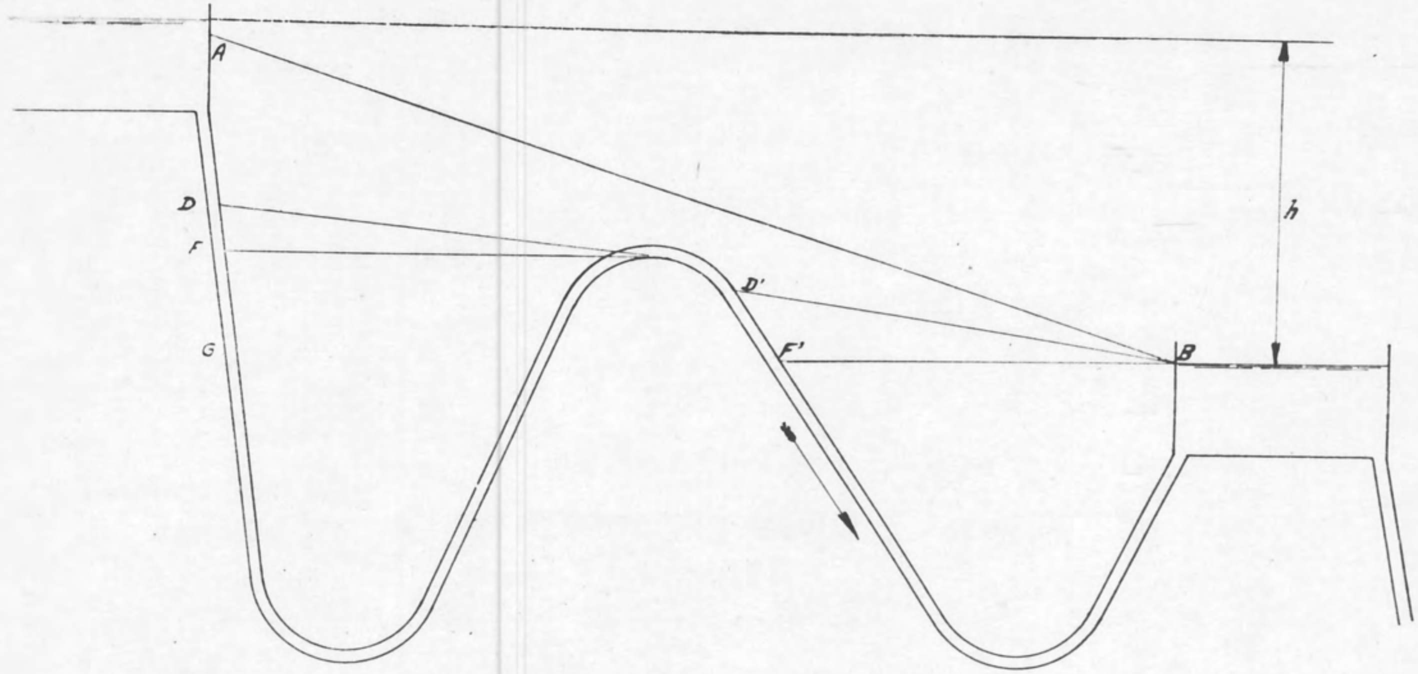

FIG n° 4

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Just as in the case of a canal with upstream control, the conduit contains relatively little water at zero discharge although it is full at high discharges. In order to increase discharge it is necessary to turn out at the head end not only the new discharge desired but in addition a certain volume to place the conduit in its new regimen. These variations between the discharges conveyed and the volumes contained in the installation will be found to be in the wrong direction, which have already been discussed. Corresponding to this situation which seems to be typical of upstream control there is a retardation in the transmission of discharge increments and in consequence a lack of flexibility.

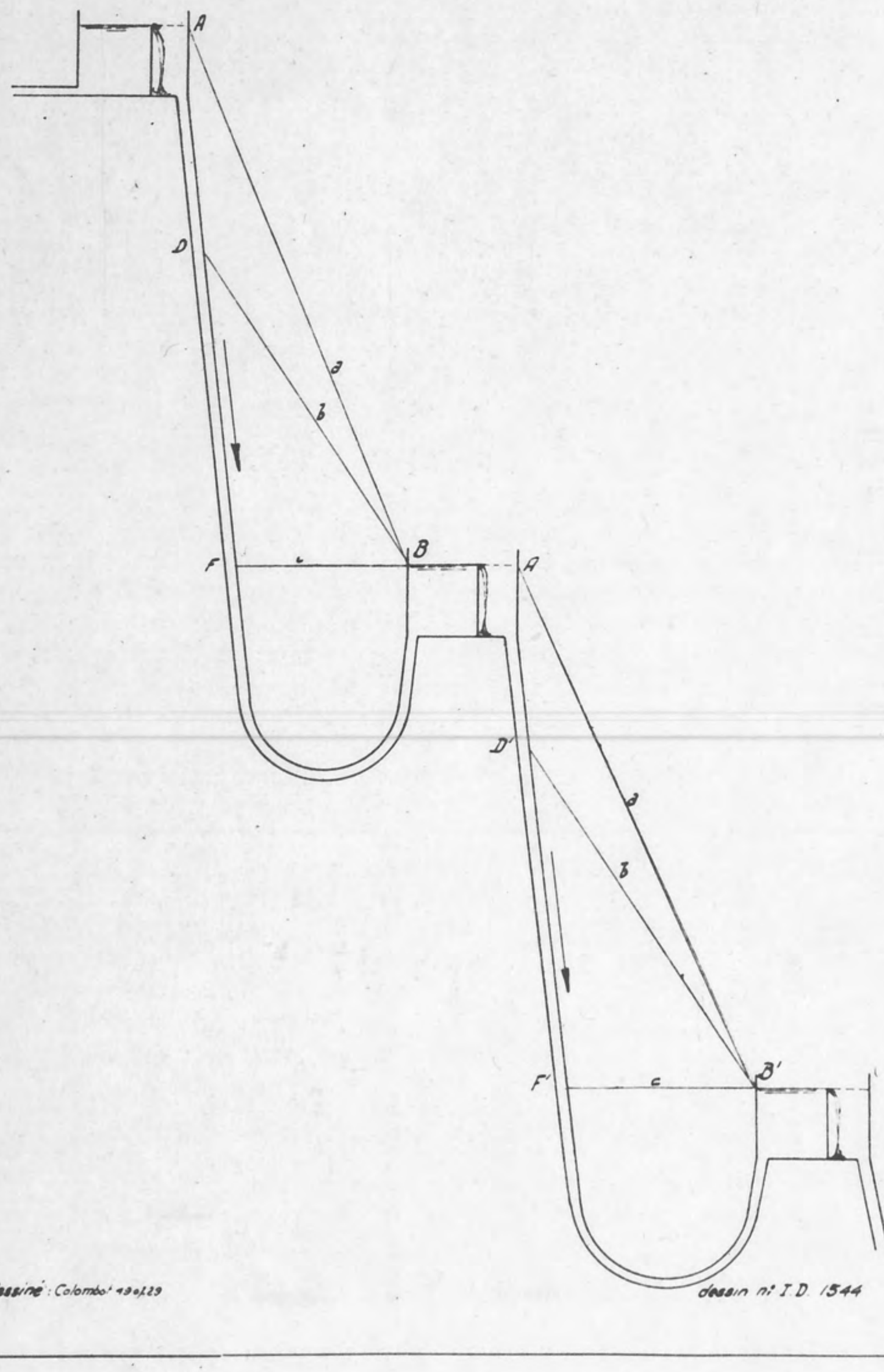
It is true that the amplitude of the variations in volume can be decreased by arranging to have the conduit as full as possible for no-flow conditions. The classical solution consists of dividing it up in sections ending in a separation basin having a free surface. These basins have a similarity to diversion weirs about which we have spoken in connection with canals. They even contain usually a weir which divides them into two parts as shown in Figure 5.

It is evident that to obtain the maximum discharge of the installation these weirs must be placed approximately on a line corresponding to the hydraulic gradient at full discharge. In this way the cascading would be eliminated at least for full discharge. Such basins, which seem to improve conditions, offer then the greatest advantage in connection with air circulating in the system. We will speak about air presently. They do introduce, unfortunately, a new inconvenience which is instability. Computations as well as experience show that conduits with upstream control separated by basins present characteristics of instability such that the change from one regimen to another must be approached cautiously and must always be carried out very slowly.

The foregoing considerations have indicated simply that in a conduit with upstream control the flow organizes itself in a rather undesirable fashion. However, the really serious nuisance derives from the presence of air. This undesirable fluid complicates many of the hydraulic phenomena described above. We noted at the beginning of this paper that in the upstream portion of the conduit one must distinguish between two parts; one, where the water cascades and one, where the water is under pressure. The zone of separation moves upstream as the discharge increases and a very turbulent condition exists there. Although it is easy to conceive that air is entrained at this point it is much more difficult to know what becomes of this air during its travel downstream. Separations of air and water will take place according to the profile and air pockets will appear temporarily at certain points. Profiles similar to the one shown in Figure 4 seem to be particularly delicate with respect to air troubles.

CONDUITE EN COMMANDE PAR L'AMONT

FIG. n° 5



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We cannot discuss the numerous details of the subject but can say only that ruptures are not rare in conduits where air is involved. We will terminate this examination of conduits where the discharge is regulated by a single gate placed at the head end by stating, as we did for canals, that there is a discrepancy between the water turned in at the head end and the discharge required by the users. Although subject to criticism a conduit with upstream control can be used when necessary to supply a unique user (a town for example) subject to the condition that variations in discharge are rare and slowly accomplished and that the profile is not too unfavorable. To our knowledge conduits with upstream control which function in a steady way at maximum discharge are the only ones which give satisfaction.

When the take-off points are increased in number it becomes necessary to transfer control of the discharge to the users situated downstream. We will now discuss a method of regulation which resolves nicely all the difficulties.

II. Introduction of Automatic Equipment and Control from Downstream

A. Conduits Controlled from Downstream

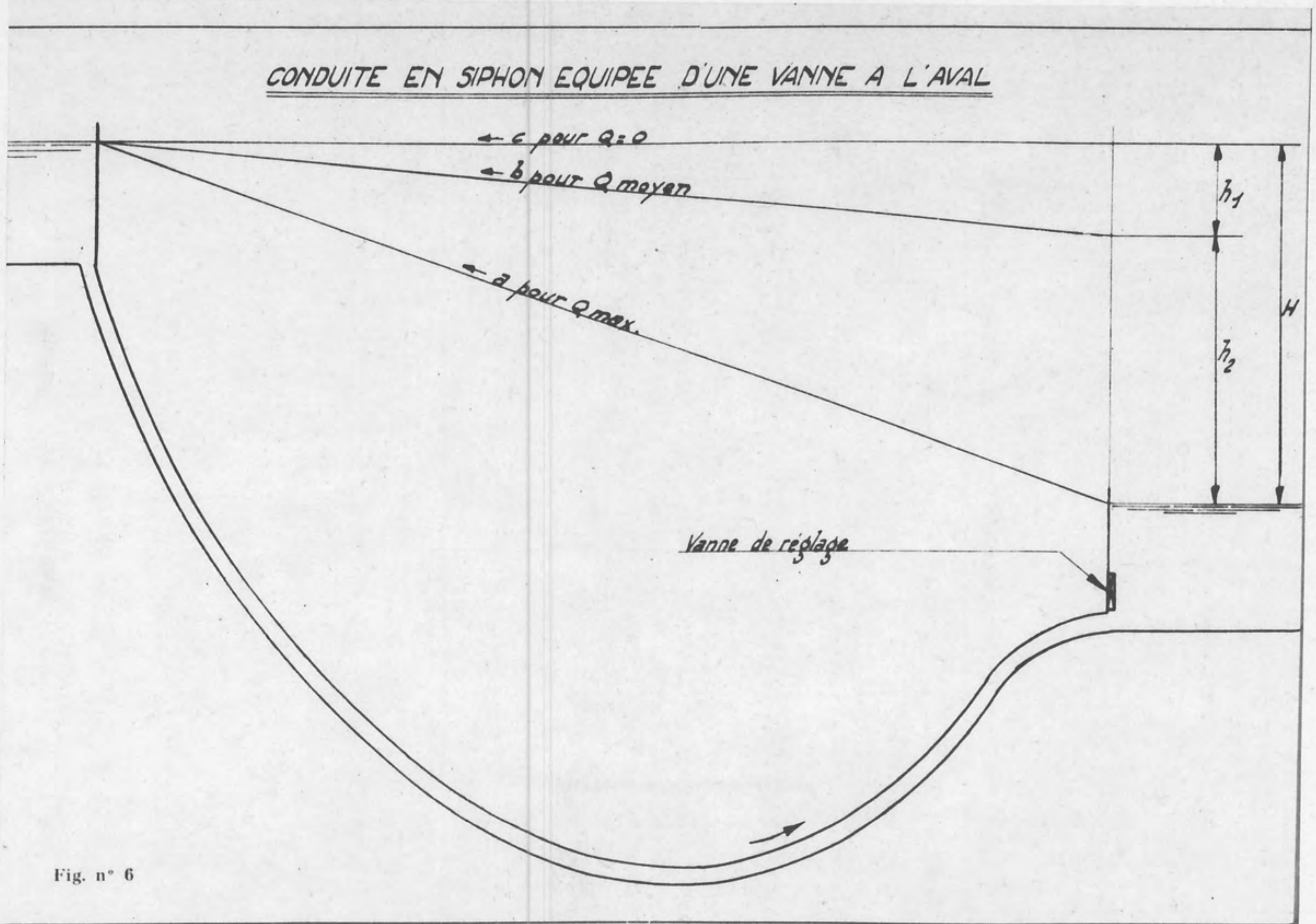
To serve as an introduction to the control from downstream let us take the siphon between two canals of Figure 3. To guard against the presence of air in the conduit would have been the first objective of a gate placed at the downstream end by the Romans. At least this is the opinion of Mr. Leger, an engineer of great erudition, who, in 1875, explained in this manner the presence of gates which were found at the downstream end of certain ancient siphons.1/ The idea of a delivery conduit of large capacity with the control downstream dates back at least to the Romans. The scheme is shown in Figure 6 where the gradients corresponding to different discharges are shown. The objective sought in this case may well have been to keep the conduit under pressure for all discharges.

The total head, h, of which we have already spoken is composed of two parts.

h_1 is the loss of head distributed linearly along the conduit

h_2 loss concentrated at the downstream end and caused by the gate which in this case was manually operated.

1/Les Travaux publics, les mines et la metallurgieaux temps des Romains, par A. Leger, J. Dejey, editear Paris, 1875.



CONDUITE EN SIPHON EQUIPEE D'UNE VANNE A L'AVAL
← c pour Q = 0
← b pour Q moyen
← a pour Q max.
h_1
h_2
H
Vanne de réglage

Fig. n° 6

The progressive closing of the gate placed at the downstream end governs any reduction in transported discharge. The gradient takes successively the positions a, b, and c. The singular loss of head, h_2, corresponds to the velocity head under the partially closed gate and the dissipation of energy in the basin. One can say that the gradient in Figure 6 rotates around the upstream level (to compare with Figure 3 corresponding to upstream control where rotation occurs around the downstream level). The static line is now situated above the various gradients and this is a characteristic of control from downstream. Besides, the conduit is always completely full of water and the troublesome effects are thus eliminated.

Actually, modern conduits with control from downstream are branched at the upstream end from a basin which is always full of water. They can discharge up to the capacity which maintains the full level. From the point of view of regulation the essential feature is not only the presence of a gate at the downstream end of the section but more particularly the fact that opening of this gate can be easily controlled automatically by the variations of level in basin into which they discharge. Thus we perceive the possibility of the automatic transmission of the downstream demand, a transmission obtained uniquely by hydraulic effects. If the discharge taken from the downstream basin decreases the level rises and a conveniently arranged float rises and causes a closing of the gate.

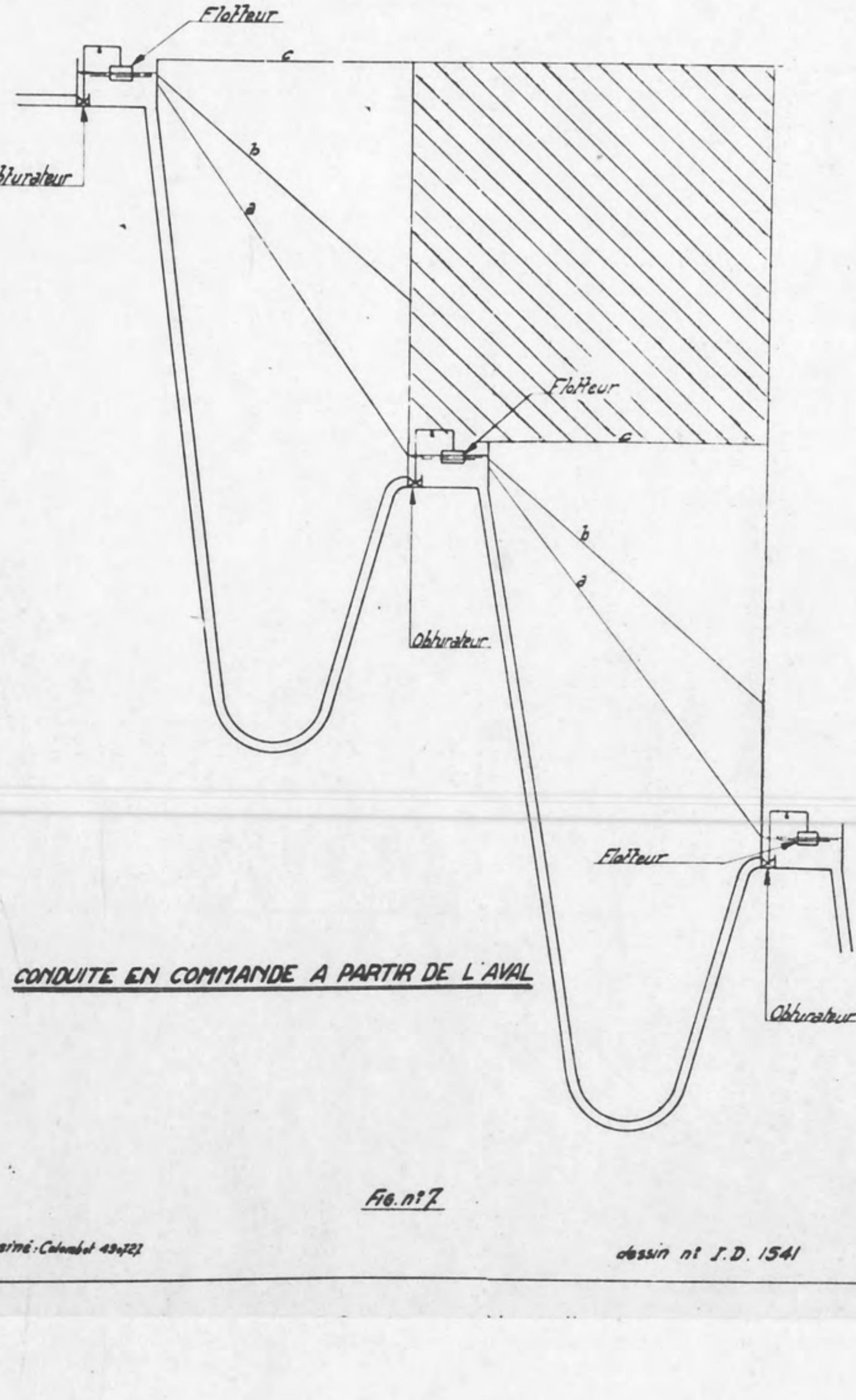
If, for any reason, one wishes to reduce to a minimum the volume of the downstream basin it must be dimensioned in such a way that the heaviest demand of the users diverting from it does not cause a drying up of the basin or oscillatory phenomena. It will be then necessary to provide in the basin a buffer volume capable of supplying the increase in demand while the water contained in the conduit acquires the required velocity. This velocity increases progressively as the gate opens under the effect of the lowering of the level which corresponds exactly to the utilization of the buffer volume. Acceleration of the water contained in the conduit is at the same time resisted by the mass of the water itself. The study of such a transitory phenomenon must include a number of factors such as the elasticity of the water and that of the conduit as well as the characteristics of the control devices. Such a study may be carried out by analytical methods.

When we discussed conduits with upstream control we noted that it was necessary to fill them more as the discharge was increased. Canals have an analogous inconvenience and we used the expression--variation of volume in the wrong sense. In the elementary installation with control from downstream now being studied it was noted that since the conduit is always full of water the only significant variation in volume is that of the downstream basin. Besides, we have just stated that the variation of this volume as a function of the variation in discharge is in the proper sense--since we have been able to speak of a buffer volume. Here then is an important statement: When the control is upstream the volume of water contained in the installation must increase with discharge; the contrary is true for conduits with the control from downstream when the water contained in the basin must decrease when the discharge increases. In other words the buffer volume corresponds to a positive reserve. The absolute value of this reserve is admittedly small but it is the positive sign which counts. It is this sign which leads to the possibility of obtaining an automatic and flexible operation.

If these aspects which have been examined above appear to be favorable other features are less so. First of all the conduit must be designed to resist a high static head plus an excess pressure caused by water hammer. We will show that this consideration can lead to a division into several segments by means of devices called breaker chambers or energy destroyers and that this division must be realized without affecting the stability of the system.

As the discharge decreases the gradient turns about its pivot and raises until it becomes horizontal at the level of static head. Without taking into account water hammer it can be said that the conduit is stressed higher at zero discharge than at maximum discharge and that the downstream end is the site of the most important variations in pressure. It is evident that if topographic conditions permit it would be advantageous to install every so often basins (Figure 7) with a free surface containing an automatic device which is analogous to the one previously described and which assure the transmission of the downstream demand from place to place. These basins which are called breaker chambers or intermediate energy destroyers must not create a significant head loss at high discharge and must be located, as in the case of upstream control, on the hydraulic gradient for maximum discharge. An economic study will balance the price of the intermediate basins and the saving in the cost of the conduit. Without accounting for surpressures, this saving is shown in Figure 7 where the cross-batched area is the amount saved from the point of view of stress. From the standpoint of water hammer the arrangement is also advantageous because the surpressures created by operation of the automatic equipment are normally related either to the length of the segment ahead of the apparatus or to the static head that the control must support. This confirmation is not self-evident but results from the study of modern regulating equipment.

One can imagine that the problems of stability are increased by the multiplication of free-surface basins as well of as moving parts. If a mathematical study of this question can be made a number of difficulties are encountered but usually it is possible to take advantage of a model study. A model is actually a veritable machine for computing conduits with multiple rupture chambers.



CONDUITE EN COMMANDE A PARTIR DE L'AVAL

Fig. n° 7

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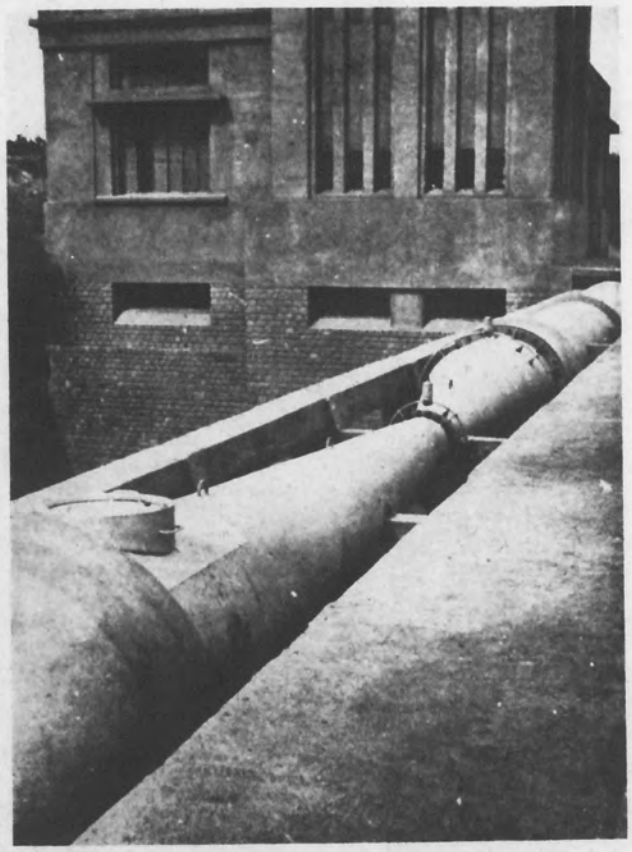
We have made a nearly complete summary of the principal questions concerning conduits controlled from downstream. Having transferred control of the discharge to the users themselves there results a perfect accord between demand and supply. The hydraulic phenomena involved are clear cut and are more or less easy to study whether there is a single conduit or a network. This is the business of the hydraulic engineer. The operator, who is also interested in the results, can see with pleasure that his work is simplified since his participation is reduced to making sure that the operations which the users are free to make, and are always evident, are carried out in such a way that the total demand does not exceed the capacity of the conduit or network. Is it not necessary that the operator superintend the functioning of such an installation? Yes, of course it is. At the same time it is possible to rely on certain devices for control and security placed at the exit of each chamber.

Since the discharge at every point, for steady conditions, is equal to the downstream demand it is possible to verify that this discharge does not exceed the maximum allowable. If this value is exceeded and if the installation is so designed that large oscillations can not occur it can be concluded that a rupture has occurred. A sector gate installed for the purpose can then interrupt the supply and stop operation of the system.

It is simple also to inspect the water surface elevation in each basin. If this one descends below its normal minimum value it is proof that the supply is failing and the same gate mentioned previously can interrupt the supple from downstream before the segments begin to function accidentally according to upstream control.

It can be said that the principle of control from downstream of large conduits is rich in possibilities. The different segments of a conduit thus equipped and the various structures which can be interspersed (hydroelectric stations, filter stations, compensating basins, etc.) make up completely independent units from the standpoint of hydraulic operation. There exists a complete interaction, along a continuous chain, for regulating the flow.

We will describe in Chapter II the conduit of Beni-Bahdel a Oran as an example. After treating this example we will undertake a comparison between the conventional system with upstream control and the system with control from downstream that we have just described in broad terms. However, before we do this in order to show a new side of the problem we are going to say a little about canals with control from downstream especially those which will be built in the very near future.



Mesure des débits dans une conduite forcée : tube Venturi de Lavigerie.

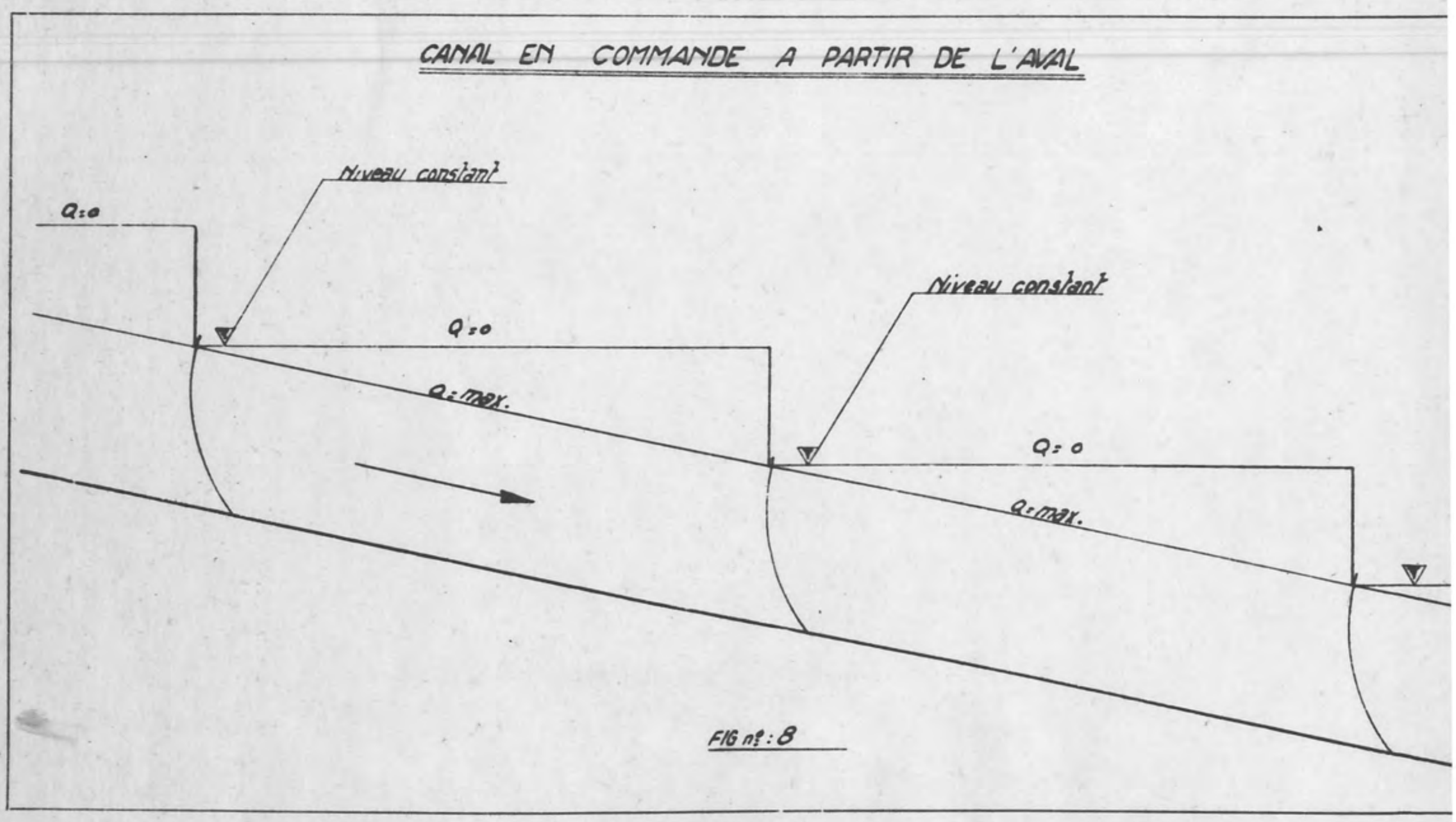


FIG nº: 8

B. Canals Controlled from Downstream

It is possible to imagine a canal divided into segments separated by automatic gates whose opening is related to the downstream level. There is a model installation at Grenoble in which the gates are arranged so that they maintain a constant level immediately downstream. The water surface varies as a function of discharge as indicated in Figure 8.

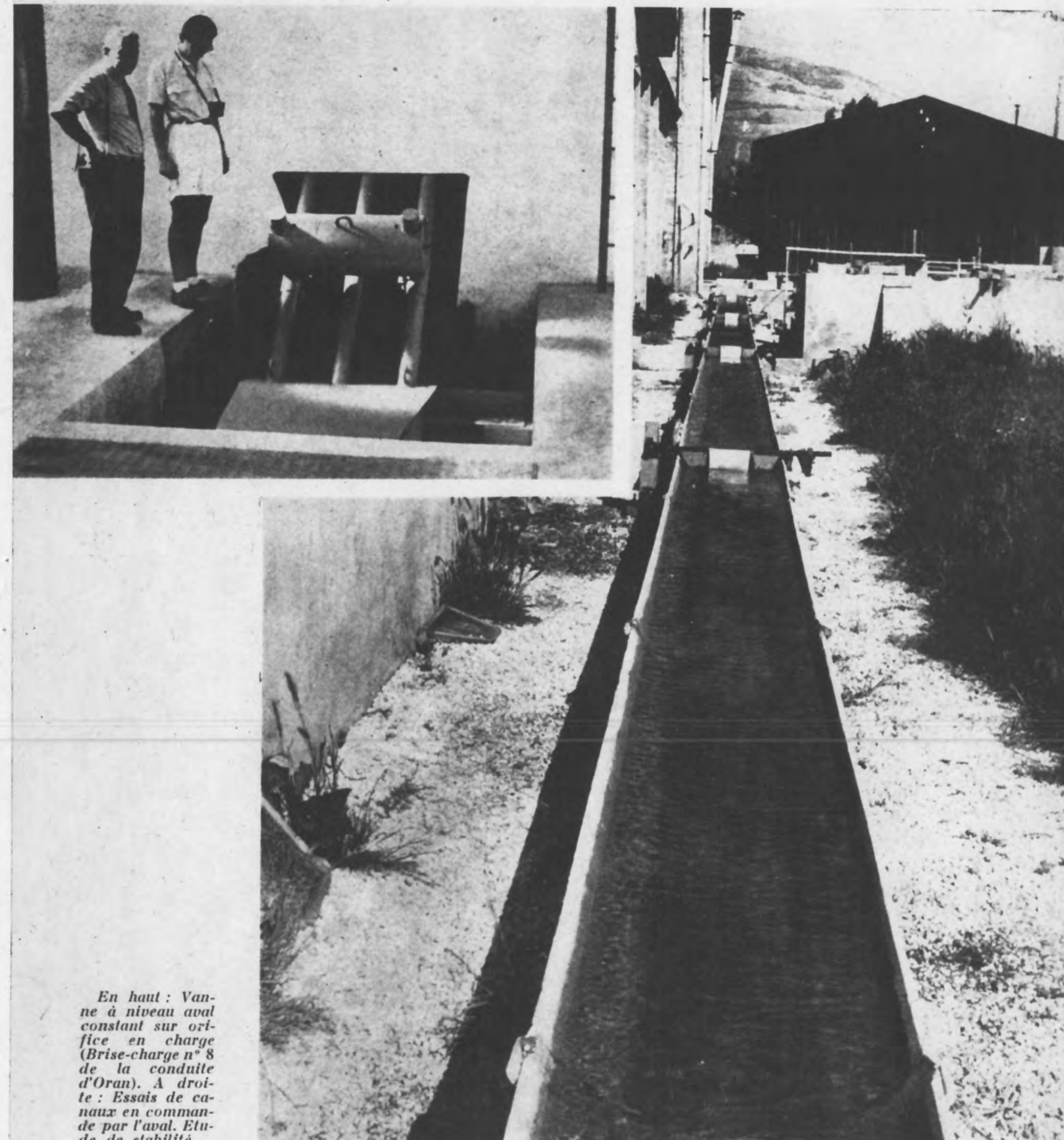
In this case the horizontal water surface for zero flow is situated above the inclined line corresponding to full discharge. Since the gates chosen have a constant level downstream (in contrast to the ease for conduits where the variation of level in the intermediate basins is fairly large) the scheme includes important buffer volumes. It is these which permit an installation of this type to operate in a stable manner.

Without dwelling on this subject which deserves a lengthy treatment, let us simply predict that regulation from downstream of canals can be applied economically only to large canals on flat slopes. Let us note that at the same time that the system assures the complete filling of the canals it also adjusts automatically and accurately the supply to fit the demand. This type of total regulation of canals shows promise for the future. Our neighboring Moroccans tell us of their success in this new approach which should be credited as much for important savings of water as for the ease of operation.

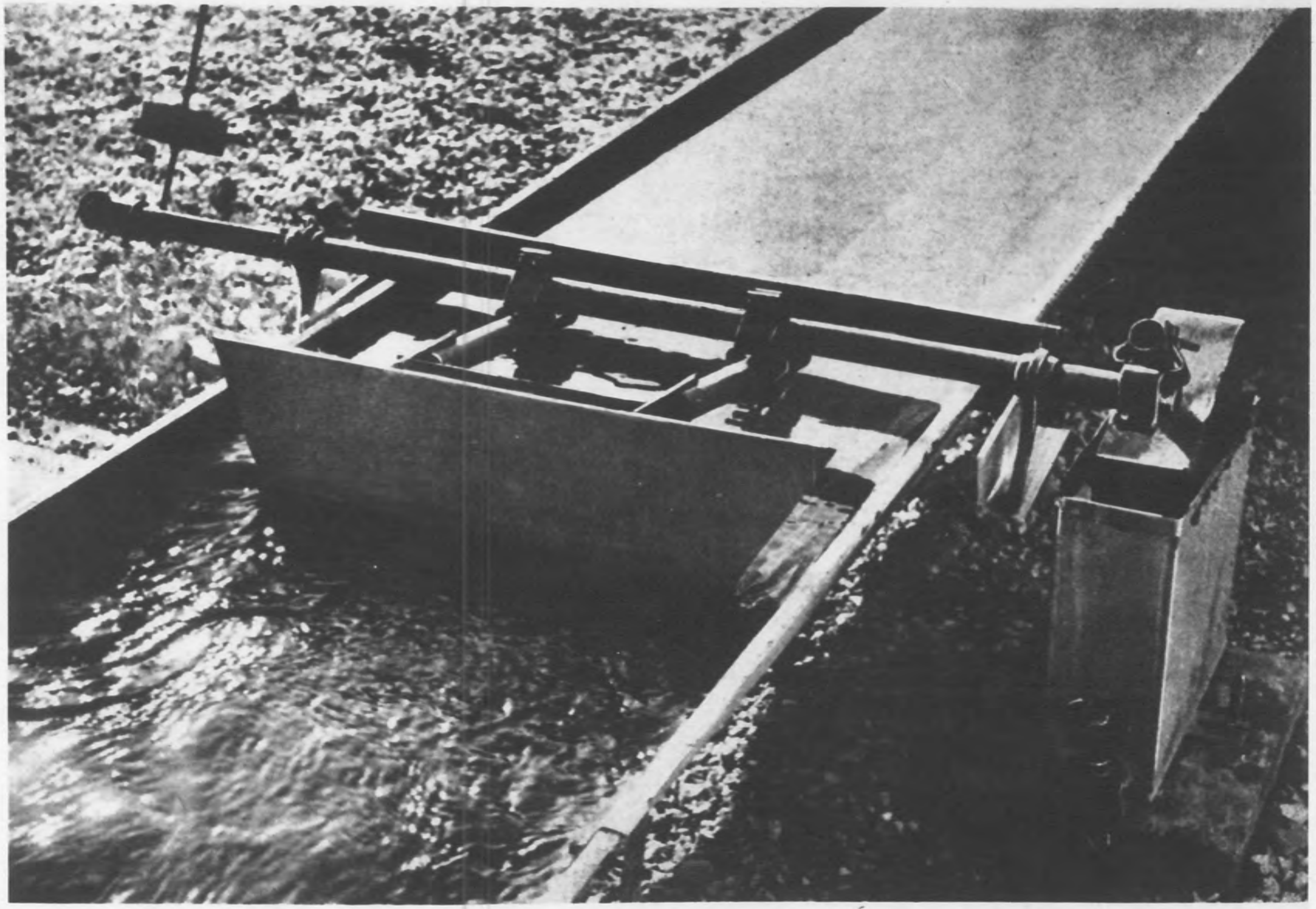
In this chapter dedicated to generalities we have had to neglect a certain number of points which could complicate the study of a specific case. We were striving to establish a general classification and to this end we have distinguished two methods which are truly different. The first method consisted of fixing the discharge at the head end and could well be regulated manually. Since the total discharge is determined at the start the means for regulating discharge in the rest of the network need be located only on the branches or at the take-offs. In principle, "hydraulic" operation does not require that apparatus be installed in the main portions of the canals. If apparatus are installed anyway they operate only to control pressures or levels. In this case it would be expected that the fixed or mobile gates would control the pressure or level upstream. Control upstream is perfectly well adapted to canals but appears to us to be less suited to conduits which involve particular restraints.

The second method attempts to carry out a true regulation in the sense that it is complete and also acts upon the discharge as well as levels and pressures. One can imagine that the arrangement can fulfill every requirement and one must provide along the installation many mechanisms which permit the users, who are located themselves at numerous points to control operation of the assembly and as a result control the magnitude of the discharge turned in at the head end. In this case the gates will have mobile components and will control a level or a pressure at the downstream side. This second method is clearly applicable in the case of conduits as the following discussion will show more clearly. For canals the same method can be used in principle and in special cases but these require further developments which we can not discuss in this paper.

Despite their appeal we can only mention for the record the systems based on a compromise between the two methods that have been discussed.



En haut : Vanne à niveau aval constant sur orifice en charge (Brise-charge n° 8 de la conduite d'Oran). A droite : Essais de canaux en commande par l'aval. Etude de stabilité.



Vanne à niveau aval constant sur canal.

CHAPTER II

APPLICATION OF THE PRINCIPLE OF CONTROL FROM DOWNSTREAM TO THE BENI-BAHDEL TO ORAN AQUEDUCT

Discussed herein is an application of the principle of control from downstream for a long supply conduit acting by gravity. A rather detailed examination of the apparatus installed at the section points will give a clearer idea of a system which was described in the preceding chapter in perhaps too abstract a manner.

I. General Data on the Problem

More than 30 million cubic meters (24,321 acre-feet) of water are delivered annually to Oran, Mers-el-Kebir and Arzew. On the warmest days of the year the aqueduct must transport about 100,000 cubic meters (3,531,450 cubic feet or 81.1 acre-feet) which corresponds to a continuous discharge of 1.16 cubic meters per second (41 cubic feet per second). Installation of the system dependent on the Beni-Bahdel dam has previously been described in this magazine;2/ we will not repeat it here. We will simply recall that there is about 12 kilometers (7-1/2 miles) from the base of the dam, a compensating basin, called Bou Hollou with a capacity of 80,000 cubic meters (65 acre-feet) and located at an elevation of 604 m (1981.60 feet). This reservoir supplies two take-offs of which one is that to Oran. Starting from here until it reaches the users taps in the city the water travels more than 180 kilometers (112 miles).

Along the route there are the following:

The filter station at the beginning (elevation 600 meters) (1968.48) point A of Figure 9

A stretch of conduit in a mountainous region

A fall of 250 meters (820.2 feet) supplying the hydroelectric station of Tessala

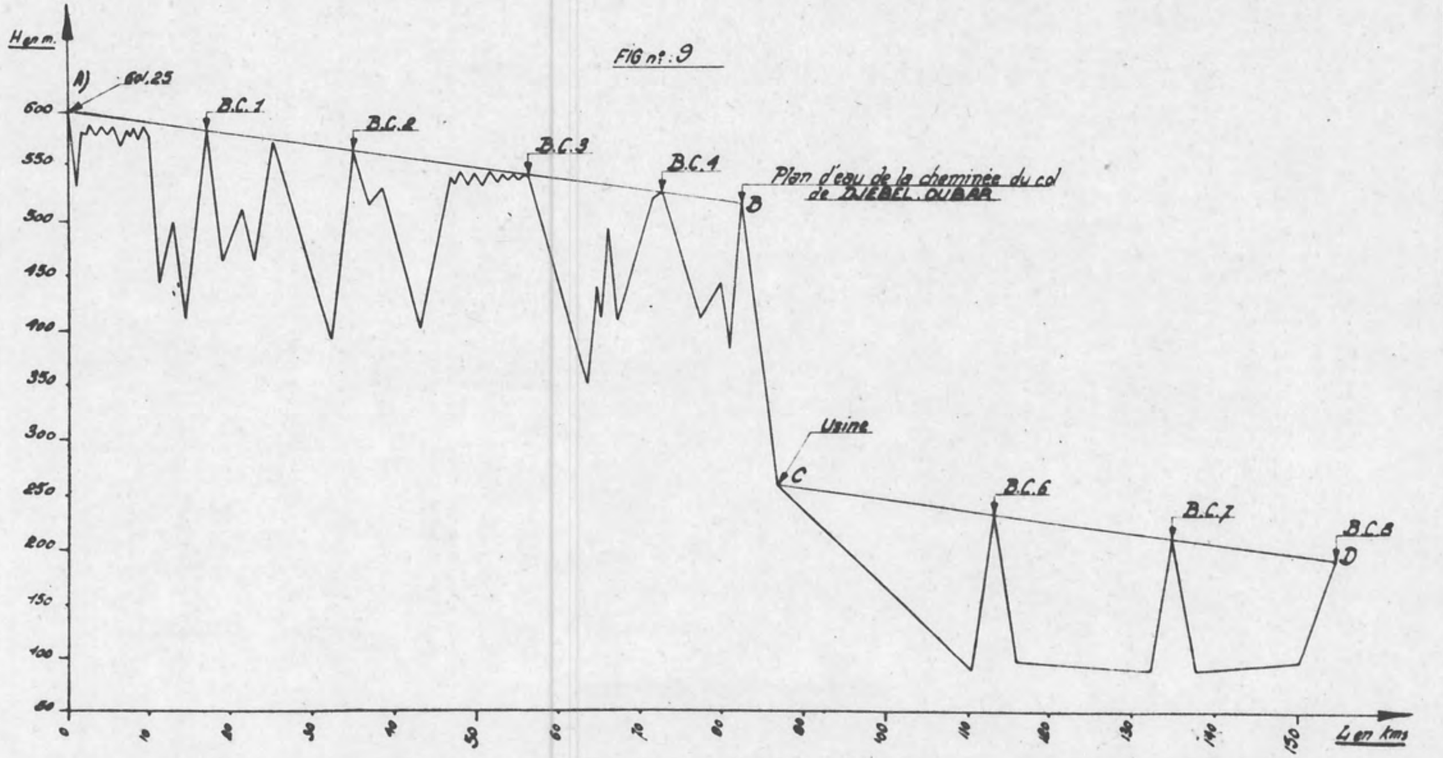
A stretch of conduit in a flatter region

The downstream end of the main conduit and the station for chlorination (elevation 188 meters (616.89 feet) point D of Figure 9)

2/See "Terres et Eaux" May-June 1948.

PROFIL EN LONG ENTRE LA STATION DE BOU-HALLOU (filtration) ET LE BRISE CHARGE N° 8 (avant ORAN)

FIG n° : 9



The principle distribution network supplying the different reservoirs of Oran

The reservoirs and the take-offs to the urban network.

Along the route take-offs are provided for the purpose of supplying several large communities.

It is useful to emphasize that Oran actually receives only water which is highly saline. The actual supply is then completely used. From the start of the studies, it was necessary to treat with care this unique and long supply line. At the same time since water is scarce in the whole region it was necessary to design a project which would avoid any waste.

The principle of control from downstream appeared to be the surest and the most flexible way which avoids all waste. The project was based on this principle. After making this decision it was proposed that a complete automatism be obtained such that between the user and the reservoir of Bou Hollou no intervention would be required for regulating the discharge.

A system was realized wherein the movement of a valve of any user reacted all along the installation across all the components which compose it, complex as they are, and made itself felt quickly at the reservoir of Bou Hollou.

We will discuss herein the devices provided for the main conduit leaving for others to describe the filter station, the power plant of Tessala and the principle network with its reservoirs in the city.

II. Description of the Main Conduit and its Equipment

A. General Plan

The main conduit is close to 160 kilometers (100 miles) connecting the take-off at the filter station to the No. 8 surge chamber where the different branches of the principle network begin. Two parts may be distinguished.

The first part located upstream from the power plant (between point A and B, Figure 9).

The second part of about the same length located downstream from the plant (C to D on Figure 9).

Study of the first part of the conduit fixed the general outline of the project. The downstream end of this part is determined by the fact that point B is the transition required by the crest Djebel Oubar which is crossed by tunnel. Points A and B with fixed elevations and distances defined the slope of the gradient for the first part of the main conduit. In determining the minimum diameter to insure gravity flow of the required discharge it was necessary to know with the best possible precision the law for loss of head in the type of conduit to be used (centrifugally cast concrete). A number of experiments were carried out in the laboratory with available pipe and the results permitted a determination of a nominal diameter of 1.10 meters (36 inches). (This diameter is slightly smaller at certain points. Where the conduit must be reinforced in special ways.)

We have stated in Chapter I that the energy destroyers must be placed on the gradient corresponding to the discharge. However, this gradient in the first part of the conduit is very near the surface at four intermediate points. At these points, after making minor adjustments in the lay-out, it is customary to install four intermediate energy destroyers. Thus the first portion of the conduit located in mountainous country consists of five segments whose lengths vary between 10 and 20 kilometers (6-1/4 to 12-1/2 miles). The fifth segment passes through point B and is projected by a pressure conduit 3,400 meters (2-1/8 miles) long to the power plant of Tessala.

To study the second part of the conduit it is first necessary to fix the slope of the gradient. The same pipes as in the first part are used and since the diversions en route are very small the loss of head per meter is quite small in the portions downstream from the plant. The elevation of the terminal above Oran being fixed (point D) it was possible, starting from the downstream end, to define the elevation of the tail bay of the Tessala power plant (point C). Thus the turbine head was fixed. This head varies from 265 m (869.4 feet) at zero discharge to 250 m (820.2 feet) at maximum discharge; the variation of 15 m (49.2 feet) results from the loss of head in the fifth segment. The gradient of the second portion is well above the ground which is relatively flat. A search for points favorable for installation of rupture chambers presented difficulties. Also, the intermediate energy destroyers in this portion are only two in number.

They define three segments with lengths between 21 and 27 km (13 and 17 miles).

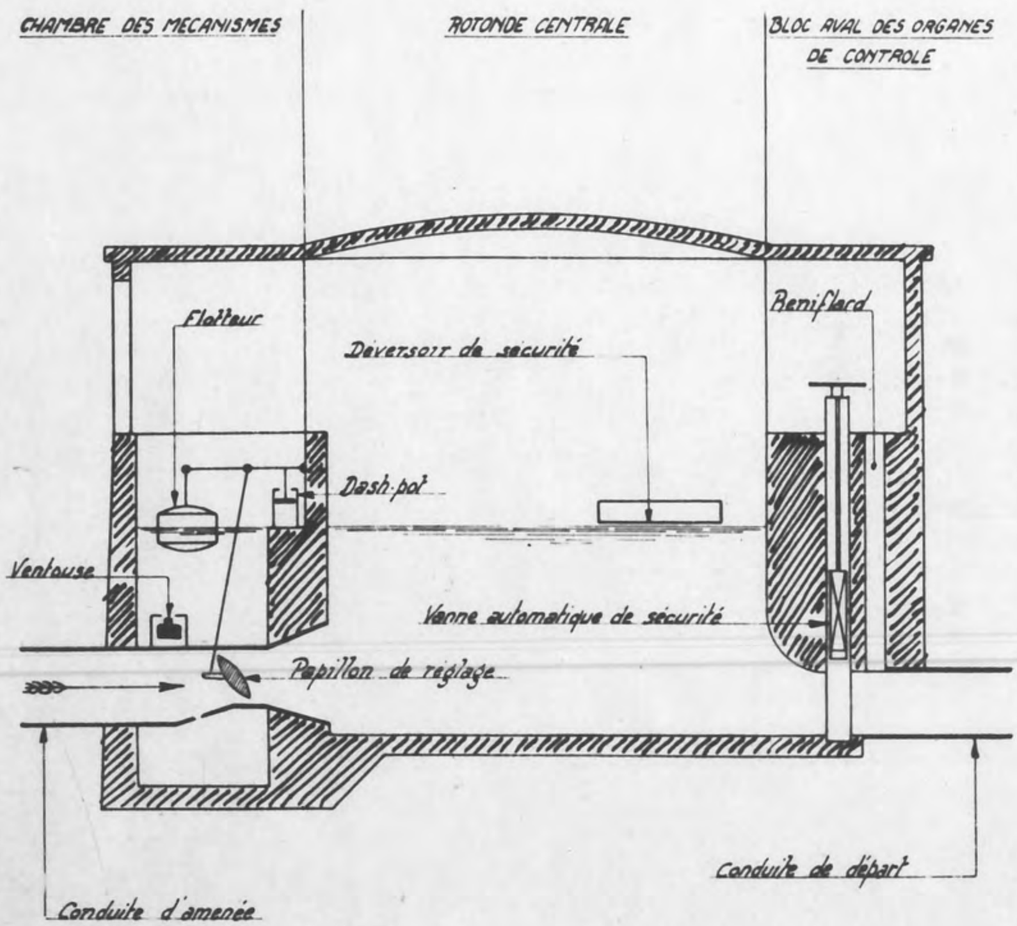
B. The Energy Destroyers (Figure 10)

In each head break there are the three following parts:

CHAMBRE DE RUPTURE INTERMEDIAIRE

(Brise - Charge)

FIG. nº 10



REMARQUE : Un second papillon plus petit muni également d'un flotteur et d'un dash-pot fonctionne en parallèle avec celui représenté sur le dessin

dessiné : Colombet 490/28

dessin nº I.D. 1542

The mechanism chamber

The rotund central part

The downstream portion and its controlling devices (Figure 10)

A. The Mechanism Chamber

We have indicated in the first chapter that control from downstream requires the installation of a regulating device, equipped with a float, at the downstream end of each segment. In the case of the Oran Aqueduct where it is desirable to have particular assurance of safety, close regulation and stability, two regulators of different size were installed in parallel.

The principal butterfly valve, 800 mm (31.5 inches) in diameter is actuated by a float through the action of a mechanical arrangement whose kinematics have been carefully analysed.

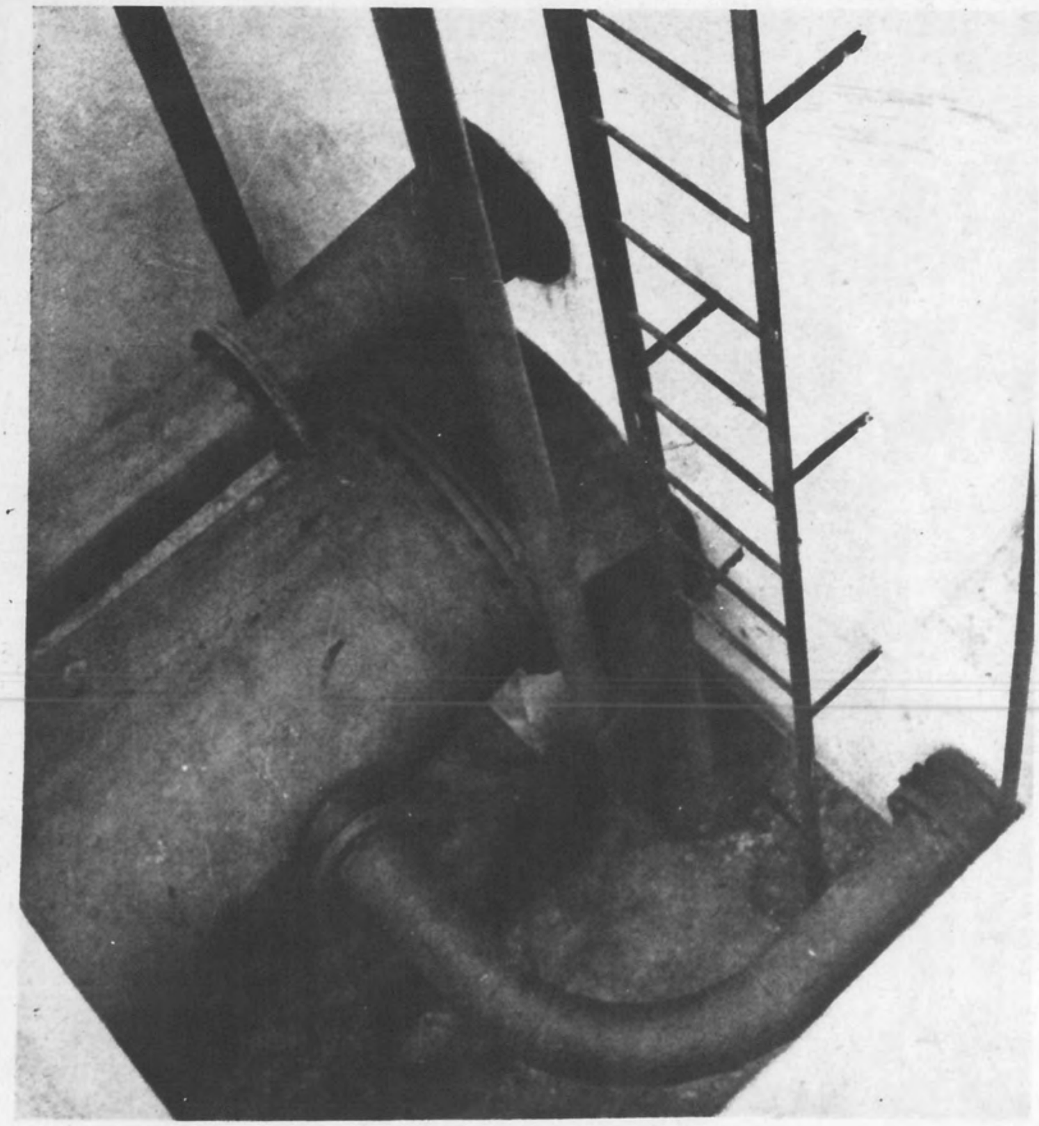
Motion of the regulating device is controlled by two dash pots at two speeds. Motions of the water surface are usually slow enough so that no large surges occur but it is necessary to protect against wedging following sudden motion. The closing velocity is limited for the case where the float is completely submerged. A single dash pot would be sufficient to limit the speed but a second one is provided for safety.

To accomplish a slower variation in discharge as a function of variation in level, a small butterfly valve of 175 mm (6.89 inches) diameter is placed as a bypass. A separate float, mechanical arrangement and dash pot completes the secondary assembly.

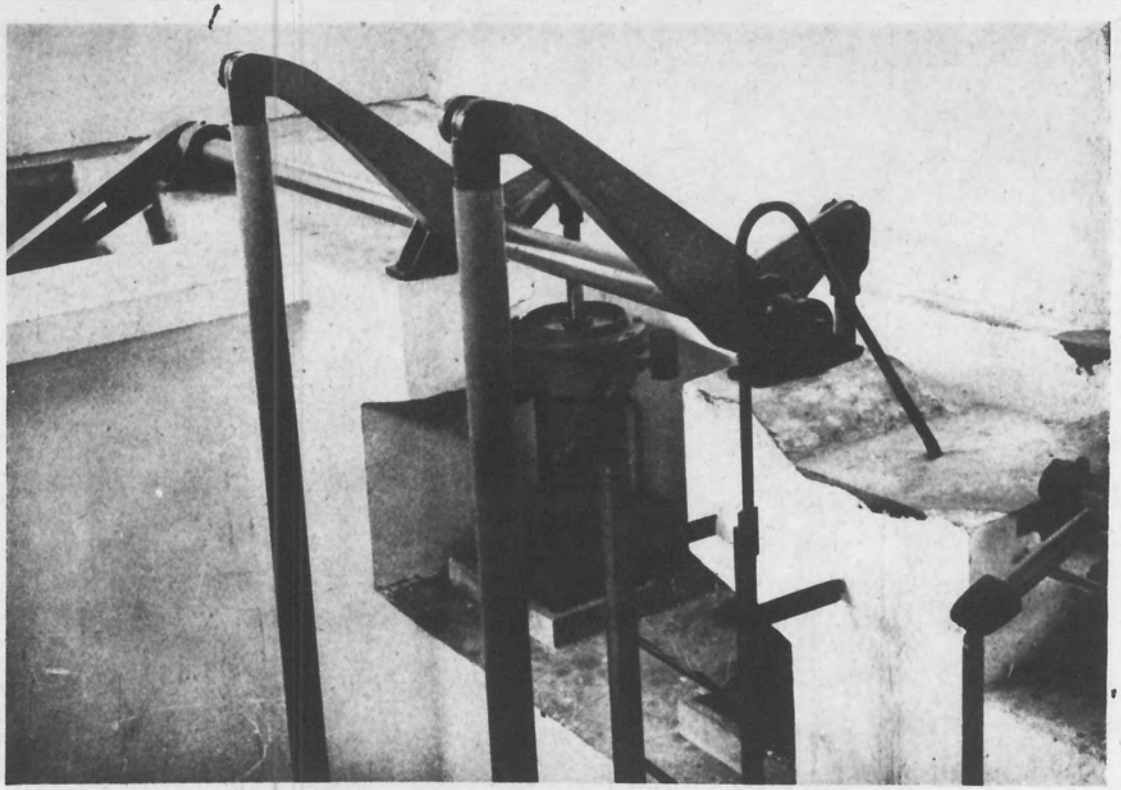
The total variation in level is 1.50 meters (4.92 feet). Below the level corresponding to zero discharge, the first 30 cms (11.8 inches) corresponds to the entire motion of the smaller butterfly valve and the remaining 120 cms (47.24 inches) produce the total motion of the principal valve. The small discharges are then delivered by the small valve which remains open when the principal valve operates.

B. The Rotund Central Portion

This is a circular basin 18 m (49.06 feet) in diameter covered by a cupola. Since the valves are submerged it was necessary to provide a certain volume in these basins to dissipate the energy liberated by the break in head (check). Besides, as we said in the first chapter,



L'une des vannes papillons de 800 $^{m}/_{m}$ utilisées pour le réglage automatique du débit.



Tringlerie de commande des vannes papillons : on distingue au second plan un des « dash pots » de freinage.

variations of a water volume (buffer) are required to protect against sudden demands and to furnish the required discharge while the water in the conduit acquires its velocity.

From a little different aspect this buffer volume is useful for stability. Comprehensive model studies have been carried out to verify the computations on this matter. These studies have shown that the dimensions shown would permit each segment of the conduit to accomplish every variation in demand without starting oscillations.

C. The Downstream Portion and the Control Devices

We have indicated in the first chapter that control from downstream permits the use of certain devices for control and security. These are placed at the head of each segment in the downstream portion of each of the head-breaks. Control is assured by an arrangement consisting of several floats in combination. These floats act in the two following cases:

1. Supply is insufficient with respect to the demand which, itself, is always less than normal upper limit

2. The demand exceeds its normal upper limit and it can be concluded that the segment being protected is ruptured.

In the first case, the level in the chamber is lowered abnormally and is easily detected. In the second case the discharge at the beginning of the segment is too large; detection is accomplished by a system of two floats acting as a differential manometer. Protection of the segment following the head-break being considered is assured by a gate of the "wagon" type. This gate automatically falls as soon as the control device opens a mechanical brake which holds the gate open normally. Closure of the safety gate suspends operation of the whole system.

Raising of the security gate requires the intervention of an inspector who must operate an oil pump acting on a hydraulic jack. This jack will act as a hydraulic brake to check the fall of the security gate.

III. Hydraulic Loading and Pressure Rises

The apparatus in the mechanism chamber is designed in such a way that normal pressure rise does not exceed 20 m (65.62 feet) at the downstream end of each segment. This valve decreases linearly in the upstream direction.

It is necessary to imagine certain accidents of a mechanical or hydraulic nature and to analyse the pressure rises to which such accidents can lead. The result of a long study for this purpose is shown and explained on Figure 11. In addition to Curve 1 corresponding to operations labeled normal, Curves 2 to 7 define the pressure rise by certain accidental operations as defined. The envelope of all the curves has been used to compute the strength of the conduit; it was necessary to resist pressure rises of the order of 25 m (82 feet) at the upstream end, 40 m (131.23 feet) in the middle and 60 m (196.85 feet) at the downstream end of a segment of medium length.

In addition to the loading from the pressure of the water that it contains the conduit must evidently be established to resist different stresses corresponding to the conditions of installation: external earth and water pressures, loading due to the passage of vehicles, loads due to temperature changes, etc.

Finally it is wise to imagine, as we did for water hammer, accidental loads due for example to the settlement or transverse movements of the soil and such other accidents as local conditions suggest.

One should mention the complexity of the ensemble and the necessity of reaching decisions based as much on good judgment as on calculation.

IV. Operating Equipment

We have tried in the foregoing pages to develop general ideas, then to describe particular points which appear to be singularly relative to large installations. We are only able then to consider in brief review the more conventional equipment along the conduit.

We will mention regarding protective equipment, that the struggle against air circulating in the conduit has been taken care of by air relief valves placed at the high points. Particular attention has been paid to the measuring equipment which, without being too expensive, tends to transform this industrial conduit into a vast permanent laboratory for determining head losses which will permit an evaluation of the changes over a period of time.

The preceding review gives an over-all picture of the design of the Oran Aqueduct. Its great length necessitates breaks and intermediate reservoirs. The various measures followed make the ensemble act as a homogeneous block which, from an operations standpoint, is exactly like a conduit without a break.

CONDUITE BÉNI-BAHDEL - ORAN

REPARTITION DES SURPRESSIONS MAXIMA LE LONG DE LA CONDUITE

Figure n° 11

COURBE 1 : Fermeture normale la plus dangereuse.

COURBE 2 : Fermeture normale la plus dangereuse avec bulle d'air au milieu de la conduite.

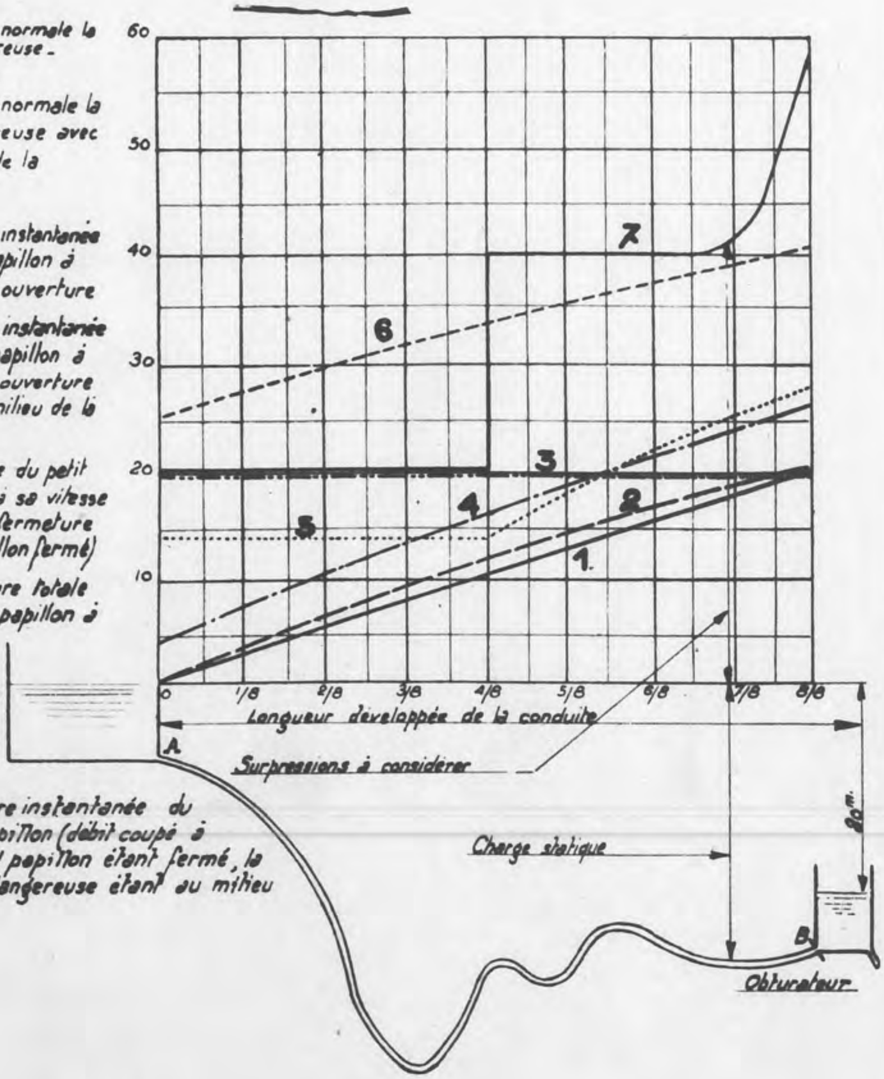
COURBE 3 . Fermeture instantanée du petit papillon à partir de sa grande ouverture

COURBE 4 . Fermeture instantanée du petit papillon à partir de sa grande ouverture avec bulle d'air au milieu de la conduite

COURBE 5 Ouverture du petit papillon à sa vitesse normale suivie de sa fermeture instantanée (grand papillon fermé)

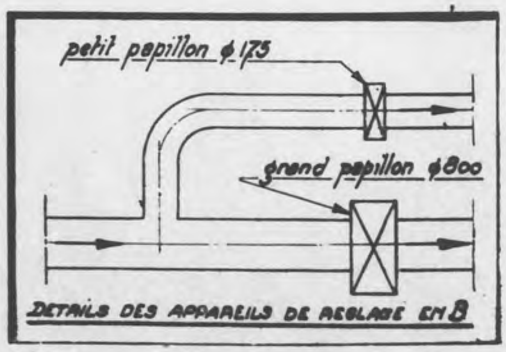
COURBE 6 : Fermeture totale du gros papillon à sa vitesse normale à partir du débit de 0,294 m³/s. suivie de la fermeture instantanée du petit papillon.

COURBE 7 : Fermeture instantanée du petit papillon (débit coupé à 0,147 m³/s) le grand papillon étant fermé, la bulle d'air la plus dangereuse étant au milieu de la conduite.

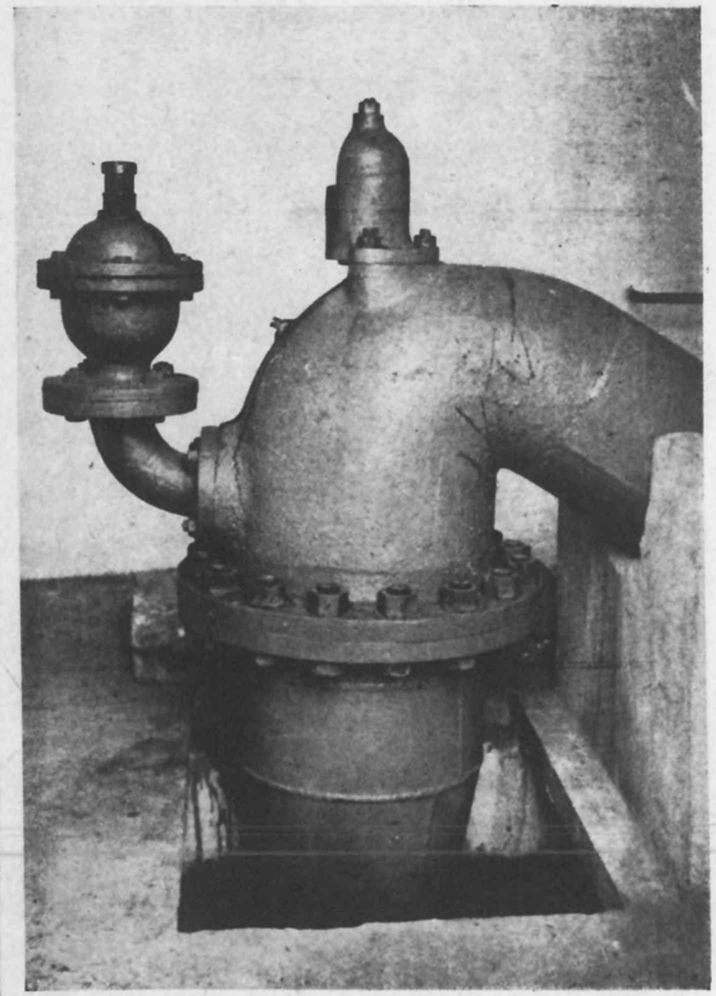


REMARQUE

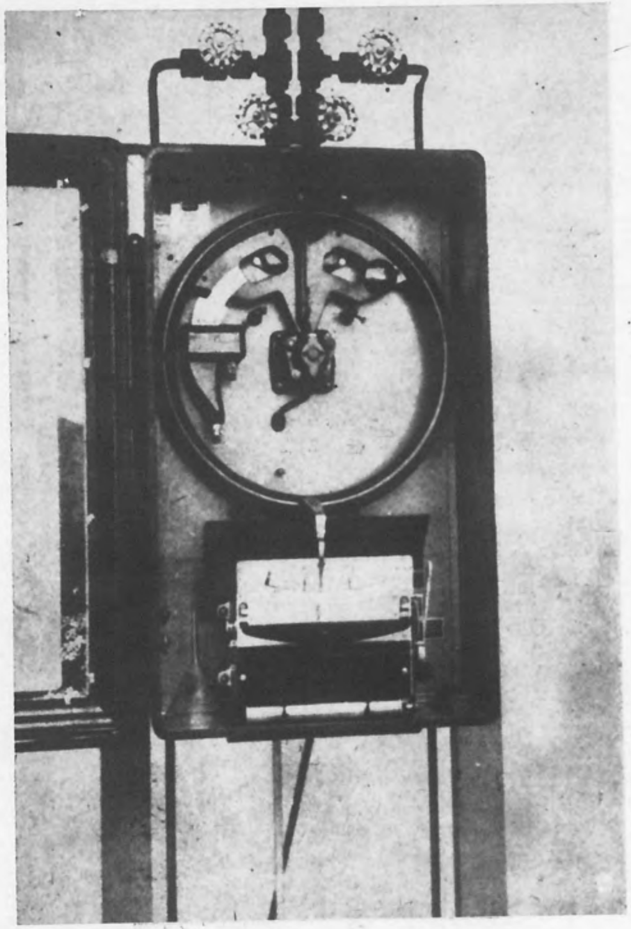
La conduite est calculée pour résister à la charge statique majorée de la surpression lue sur la ligne enveloppant l'ensemble des courbes (parties des courbes 6 et 7).



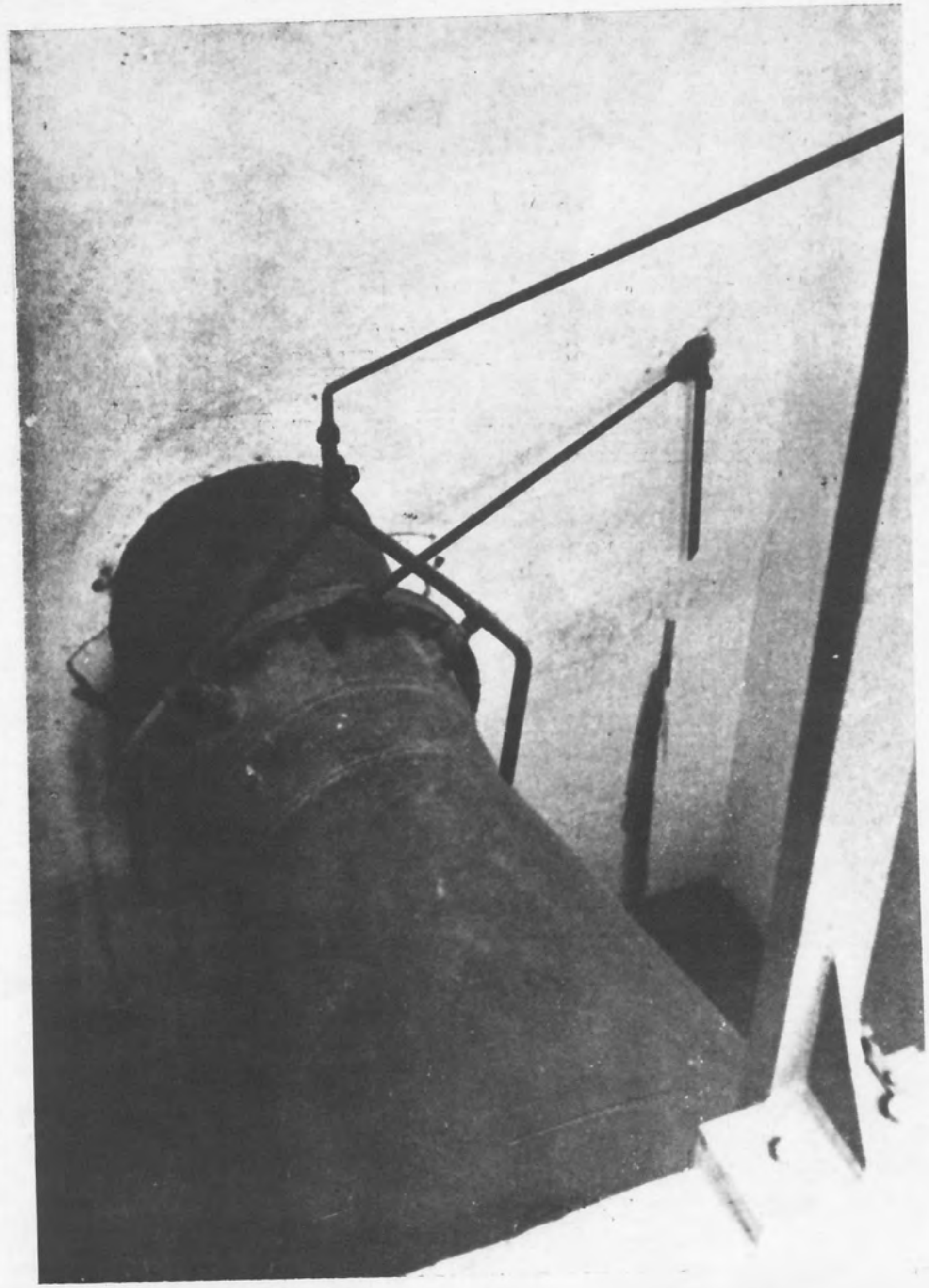
Having now acquired, by the study of a specific example, a clearer notion of the possibilities offered by control from downstream, we will set forth a comparison between this type of control and the type which may be contrasted with it.



Ensemble « Purgeur Ventouse » placé en chaque point haut de la conduite pour l'évacuation de l'air et la protection de la conduite contre les dépressions accidentelles.



Manomètre différentiel et tube Venturi utilisé pour la mesure des débits.



CHAPTER III

COMPARATIVE ADVANTAGES OF TWO SYSTEMS FOR MAKING DISTRIBUTION BY LONG CONDUITS--"UPSTREAM CONTROL" AND "CONTROL FROM DOWNSTREAM"

It may seem premature to wish to judge in too precise and definite way the advantages of one or the other system. Control upstream has had a long history since nearly all of the present systems are of this type. Control from downstream does not have the benefit of such an experience. There are a certain number of small systems and some medium-sized ones in sections. There are very few distribution systems of any size which are controlled from downstream. The conduit of Beni-Bahdel a Oran will probably be the first one of any size where completely automatic operation is realized. Perhaps our judging is a little premature but we are going to try to formulate several elements and temper our conclusions with prudence.

First we will review certain fundamental aspects of the over-all system in a general way. We will extend the comparison by examining the manner in which the pipes themselves act with respect to internal and external factors. We will end up by describing the manner by which several accessory devices, depending on the aspect being discussed, can be incorporated in one or the other system without upsetting the homogeneity.

The fundamental properties to be discussed are four in number; automatism, stability, quickness of response and simplicity. Since all of these are more or less related to the existence of reserves especially the first three, these qualities are sure to favor control from downstream. To change from no discharge to a large discharge, when control is upstream, it is necessary to fill the conduit. This observation which seems at first to be unimportant is really fundamental. With upstream control there are no reserves, or rather, they are negative. On the other hand, for installations with control from downstream not only is the conduit always full but in addition all the basins are filled completely at zero discharge. There is a positive reserve which is the secret of the flexibility of the installation.

Let us now examine the four basic qualities. Each of the following paragraphs discusses these qualities by successive comparison of upstream control (u-s) then control from downstream (d-s).

a. Automatism

u-s Upstream control requires a gate keeper to make the changes required by a supervisor located downstream. It adapts itself to only a limited automatism.

d-s With the control from downstream automatism may be very generally realized. A simple maintenance survey is to be expected.

b. Stability

u-s Experience shows that to change from a small discharge to a larger one it is necessary to make changes at the head end very slowly. Computations explain the action and indicate that fluctuations are started very easily in the first segment by each variation in discharge. The variable discharge feeding into the first basin, dividing the system, can amplify the fluctuations in the following segment and thus it continues so that the third or fourth basin spills over or goes dry alternately in a disconcerting fashion. On these oscillations of mass are superimposed the action of captive air pockets to complicate the phenomena.

d-s On the contrary it can be said, and computations can be made to insure correct operation in large lines, that with control from downstream the operation is stable under the condition that certain proportions are preserved. The advantage on this score can then be considerable. Computations or extensive experiments should be carried out to define the conditions for stability.

c. Rapidity of response

We shall designate by time of response the time interval which passes between the instant at which the need for water makes itself felt and that at which the demand is fully satisfied.

u-s For upstream control it is not necessary to hurry or to predict the needs in advance. Actually, the time required to telephone the gate keeper upstream, the time required to make changes with the slowness that insures against undesirable oscillations, the time required to complete the filling of the conduit, all of these add up to a considerable delay which is counted in hours.

d-s On the contrary, with control from downstream the demand can be satisfied instantaneously if so desired. In practice, in order to decrease the volumes of water acting as buffers, the response time is made somewhat greater than zero but does not exceed several seconds.

d. Simplicity

u-s It is apparent that upstream control which requires no mechanism for regulating (except for the case of a gate at the head end) is the simpler system.

d-s Even though with control downstream the mechanisms provided are more numerous the phenomena involved are more straightforward and operation is much simpler.

Since the pipes themselves constitute the foundation of the installation we will now examine their action with respect to head, overpressures (water hammer), entrained air, and pollution from outside. We will also examine the risk of rupture introduced by the system of control and the precautions which may be taken.

e. Pressures for normal operation

u-s We have already stated that the hydraulic gradient for full discharge determines the loading which must be considered in designing the pipe.

d-s In contrast to the preceding case the design of a conduit with control from downstream is based on the static head exerted when the discharge is zero. This head is greater than the preceding one. It can result, depending on the case, in appreciable differences in the cost of the conduit.

f. (Overpressures)

u-s A system equipped for upstream control does not have a shut-off at the end of each segment. One is tempted to conclude, and not without reason, that overpressures cannot occur. But one would be drawing conclusions without considering the presence of air which, as pointed out before, can produce important overpressures that are very difficult to correct.

d-s With control from downstream there are numerous gates whose movements create surges in pressure. However, since the operation of these gates is well known and the choice of type is open, it is possible not only to compute the variations beforehand but even to reduce them.

g. Presence of air

u-s We have seen that for discharges less than maximum a portion of the conduit is not full. When there are parts of the conduit above the downstream level several portions may be partially full. In these cases there are important air pockets in the conduit. Besides in the unfilled part, the water cascades. At the junction with the part of the conduit under pressure air is entrained as bubbles by the high velocity jet. The bubbles may be dissolved at points where the pressure is greater then reappear farther on in the form of a fine emulsion. It is apparent that the presence of air distributed in the water can easily lead to the formation of air pockets at the high points of the conduit. These pockets of air formed in one way or another constitute a triple danger:

They amplify the action of oscillation of the masses

They amplify even more so the water-hammer waves

They can also create surpressures by the action of phenomena which accompany the operation of air relief valves.

d-s In a system controlled from downstream nothing similar can occur. Air is not admitted except when filling after the system has been drained. Filling is accomplished from upstream and the conduit functions temporarily as one with upstream control. Certain precautions would be taken on these rare occasions.

h. Pollutions en route

u-s Parts of the line are at atmospheric pressure for medium and small discharges. If these parts are immersed in the water table the outside water can penetrate to the interior and pollute the water being transported.

d-s A conduit controlled downstream will generally be subjected at all points to sufficiently high heads so that any leaks will flow from inside to outside. This is an indispensable condition for conserving the purity of the water.

i. Ruptures

u-s If an element of a conduit with upstream control should rupture there is no automatic arrangement that can detect the accident. As soon as he finds out, the gate keeper will close the gate which he supervises. However, because of the long time of response the effect of the closure takes a long to make itself felt. Ruptures occur, unfortunately, in these installations, relatively frequently in fact.

d-s With control from downstream the velocity of the water at every point in the conduit and in particular at the upstream end of each segment is rigorously related to the discharge demanded downstream. In case of a rupture this velocity takes higher values and it is possible to interpret this as evidence of a break. It would then be possible to place at the beginning of each segment an automatic gate called--for control--which closes itself when the velocity exceeds a given value.

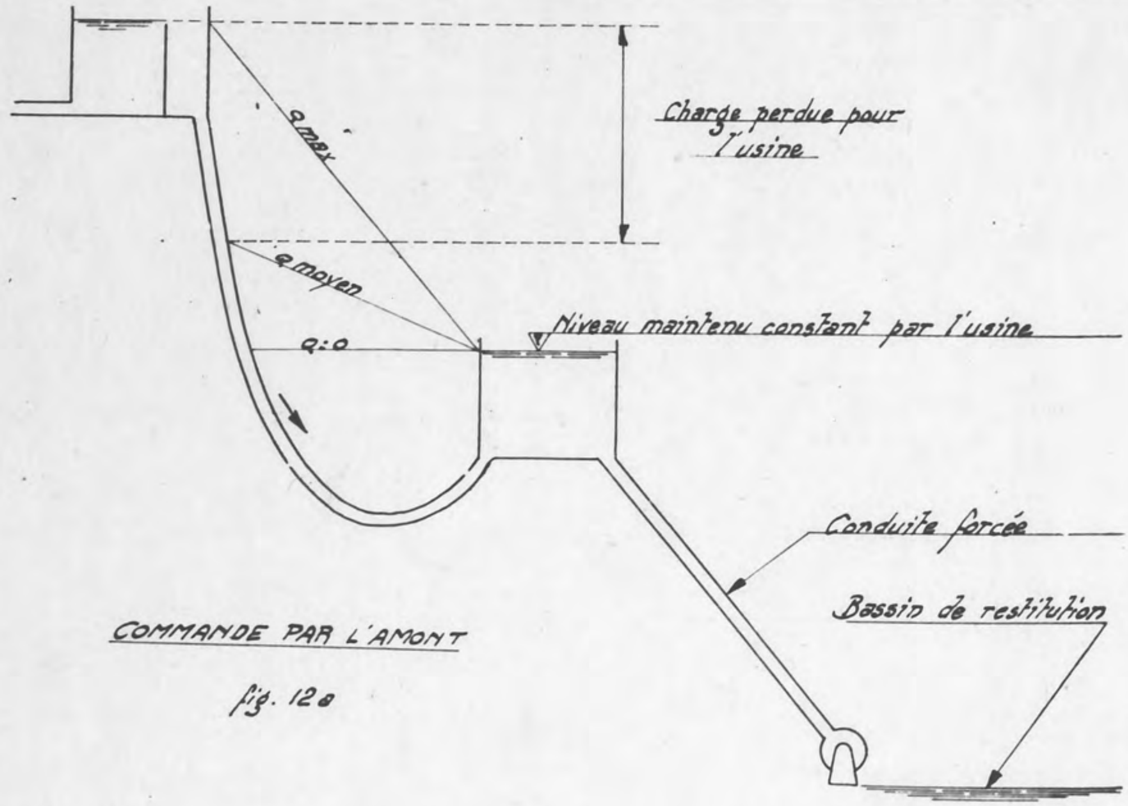
One can thus use the more effective devices which are conventional for pressure conduits to limit the damage caused by a rupture. Ruptures due to water hammer are rare in conduits controlled from downstream. Certain parts may be broken for different reasons and usually for definite reasons--faults in design or fabrication of the conduit or the apparatus, faults in operation and, especially during filling sudden obstructions due to foreign bodies, shocks from the surroundings, etc. Also, bombing might be imagined. We will now take two examples of auxiliary installations that one wishes to insert into a system of distribution by conduit: a hydroelectric plant and a filter plant.

j. Hydroelectric plant

In the case where a break in grade occurs along the profile we might place a hydroelectric station at this point.

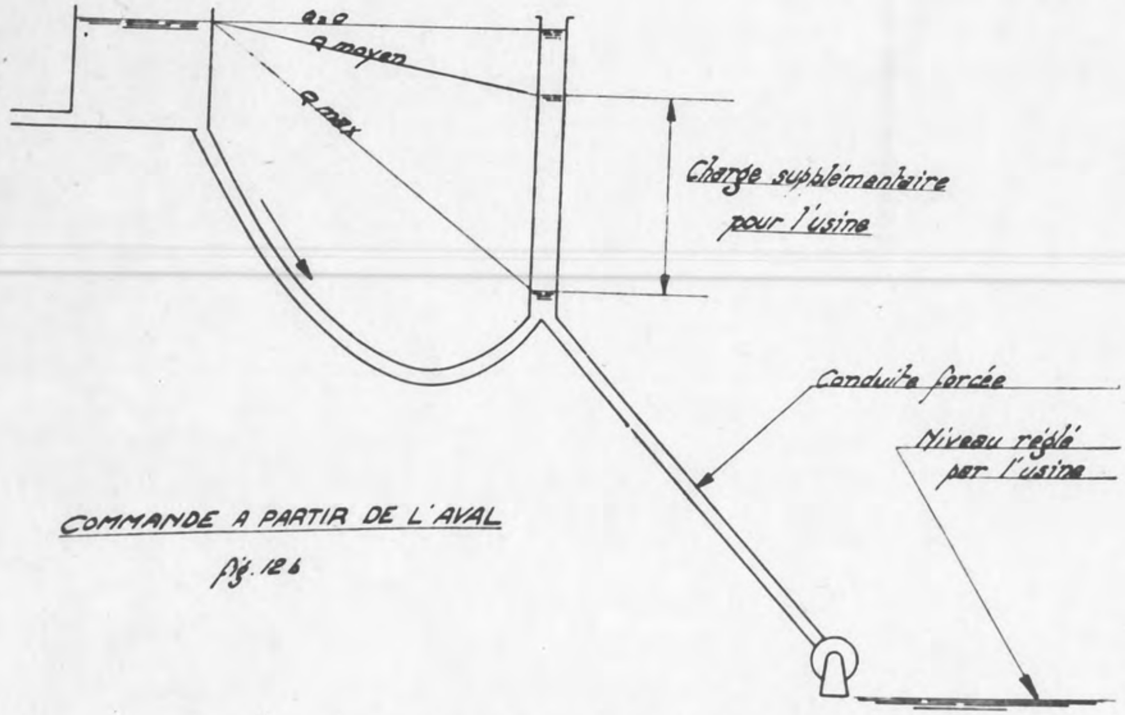
u-s With upstream control the turbines must adjust their discharge to the discharge furnished by the preceding segment in such a way as to operate under the greatest possible head. The turbines regulate the level in their forebay which can be somewhat remote. When operating at a discharge less than the maximum, one can see from Figure 12a that a certain head is dissipated in the preceding segment in the form of a cascade. A certain amount of energy is then lost.

d-s With control downstream the problem is simpler because an installation containing a turbine constitutes one element of control from downstream. It would then fit naturally into the assembly based on this principle. Turbines will maintain the level in the tail bay (which is immediately downstream). One will note in Figure 12b that there has been provided between the end of the preceding segment and the beginning of the pressure conduit an equalizing chamber rather than a rupture chamber. This method permits utilizing in the turbines the increase in pressure corresponding to the decrease in head loss for medium discharges.



COMMANDE PAR L'AMONT

fig. 12a



COMMANDE A PARTIR DE L'AVAL

fig. 12b

COMPARAISON DES LIGNES PIEZOMETRIQUES DANS DES INSTALLATIONS A COMMANDES PAR L'AMONT ET PAR L'AVAL

FIG. nº 12

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k. Filter station

Operation of filter stations always corresponds, to our way of thinking, to our definition of control upstream. Automatic equipment can be developed more or less depending on the installation. It is interesting to note that at the start of the studies of the Oran supply the idea of a filter station with automatic control from downstream was suggested. In solving this problem the best arrangement has been found to be more of a downstream control. Equal distribution of discharge among the different filter elements is obtained automatically and simply. The parallel arrangement serves as a self-correction for silting. Several secondary effects favorable to security of operation are also realized. The solution is independent of the number of filter stages as the control is transferred from one to the other. Several filter stations with automatic control from downstream have been built or are under construction. The results obtained are remarkable.

When it is a question of inserting a filter station in a distribution system, either controlled upstream or downstream, there are available control equipment which is simple and well adapted. This permits the application of the type of control adopted for the station and the suppression of the effects of a break in continuity of the system.

In planning long-pressure conduits in which the flow is accomplished by gravity and providing for the equipment of all the auxiliary stations (filter plant, hydroelectric station, compensating basin, etc.), one should consider using control from downstream in each case. From the preceding discussion we consider the following two points to be the most important factors in favor of downstream control:

1. No human intervention is necessary under normal conditions which results in a very simple operation.

2. The straightforwardness of the hydraulic phenomena involved assures that the various maneuvers are carried out without a hitch. The smooth hydraulic operation constitutes a guaranty of uninterrupted performance.

There is one important aspect to be examined in each special case, the first cost. This cost depends largely on the pipe cost and somewhat on the equipment cost. The pipes are not necessarily thicker walled and more expensive for downstream control than for upstream control. If the profile is only slightly uneven or when the gradient is flat, the heads for normal operation are not unfavorable for downstream control, especially since surpressures are small and well defined in these cases.

The cost of the mechanical equipment and the corresponding engineering costs represent only a small portion of the total. This expense can be minimized by simplifying the mechanisms much as possible, keeping in mind that proper hydraulic operation of the apparatus is of first importance. On this depends the soundness of the system.

Without trying to foresee the future too clearly it seems to us that in most cases the decision will be in favor of control from downstream assuming that arrangement may be made at the head end for a reserve sufficient to supply the demand.

CONCLUSION

The problems of conveying water supplies over great distances has led, since early antiquity, to major engineering works. The Roman aqueducts whose ruins ornament the Tunisian countryside are proof of this. These imposing works naturally disclose certain imperfect techniques. The Romans as well as their predecessors had gone a long way in the domain of hydraulics but the materials known to this era limited the master builders. It was impossible to build large pressure conduits so they were forced to use canals.

Thus the water supply systems had to meander at the will of the contours at the price of considerable elongation of profile.

To avoid long detours and to span ravines they had recourse to arcades whose majesty served to glorify the empire. In addition, the problem of regulation did not trouble the Romans. They used only compensating weirs and few reservoirs at the head end. The water supply generally originated from a source the total discharge of which was conveyed.

On the contrary, the dams used in our times must compensate supply and demand. One undertakes to store water during periods of low consumption to be used in the warm months; this poses a problem of flow regulation.

The Roman siphons of Tebourba, Constantine and Lyon show an example to be followed but it is necessary to look to the seventeenth century to find cast iron siphons connecting segments of a canal, then little by little the conduits replaced the canal over its entire length. This was the continuous system of conduits which has been so greatly extended in our time. This approach permitted a freedom of alignment which in plan is straighter and thus shorter even though the profile is uneven since it follows the topography.

Yet the discharge is still determined by the quantity turned in at the head end, the point where a regulation device is eventually located. We have called this method of regulating discharge--control upstream.

Although this system solves many problems of alignment and permits control of discharge to a degree, it introduces undesirable factors because there may be important water hammer effects and instability in the flow. These features are the consequence of the principle followed because of the fact that one admits to the conduit in addition to the water to be transported an undesirable fluid which is air.

Considering such a conduit, there has been an attempt, continuing for many years, to find a better solution of the regulating problem of long delivery systems by using control from downstream. This system was inspired directly by urban networks wherein the conduits are under pressure. It presents advantages which are due, in particular, to elimination of the air. It assures at the same time a continuity in the transmission of pressure to such a degree that the water contained in the conduit is utilized to transmit from downstream to the upstream portion the information regarding the needs for water in the downstream portion.

The throttling device placed at the downstream end was first regarded as an undesirable factor, more apparent than real because when the throttle is closed the conduit is subjected to relatively large static head. However, the use of prestressed concrete has led to the idea, since inception of the project at Oran, that it is not necessary to put up with this inconvenience.

Studies and experience have shown that such a type of regulation will permit the occurrence of pressure surges, that is water hammer effects. These may be reduced to such a degree that the inconvenience due to the increase in head is quickly suppressed and in any case dies out in the next stage when the conduit is divided into segments.

One cannot fail to be impressed by the mass of water in motion which in the case of the Oran Aqueduct is more than 160,000 tons, or more than four times the mass of the battleship Richelieu. In order to retard or accelerate such a mass without causing dangerous pressure surges it is necessary to dominate its movements completely and, in particular, to know how to avoid setting the system in oscillation. Studies combined with experiment inform us on this score.

The very fine work at Oran has attracted great interest and the example will be copied. Thus, the Tunis Aqueduct will be constructed according to a similar scheme. In this field, Algeria is clearly in the lead. The completion and operation of the Oran Aqueduct represents the culmination of the studies and the design work carried on by the engineers and contractors to aid the Colonization and Hydraulic Service (of Algeria) to solve the grave problem of a water supply for Oran.